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Conservation
Research
Report Number 42

November 1995

Crop Residue Management To Reduce Erosion and Improve Soil Quality

North Central

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Crop Residue Management
Land Resource Regions of the United States

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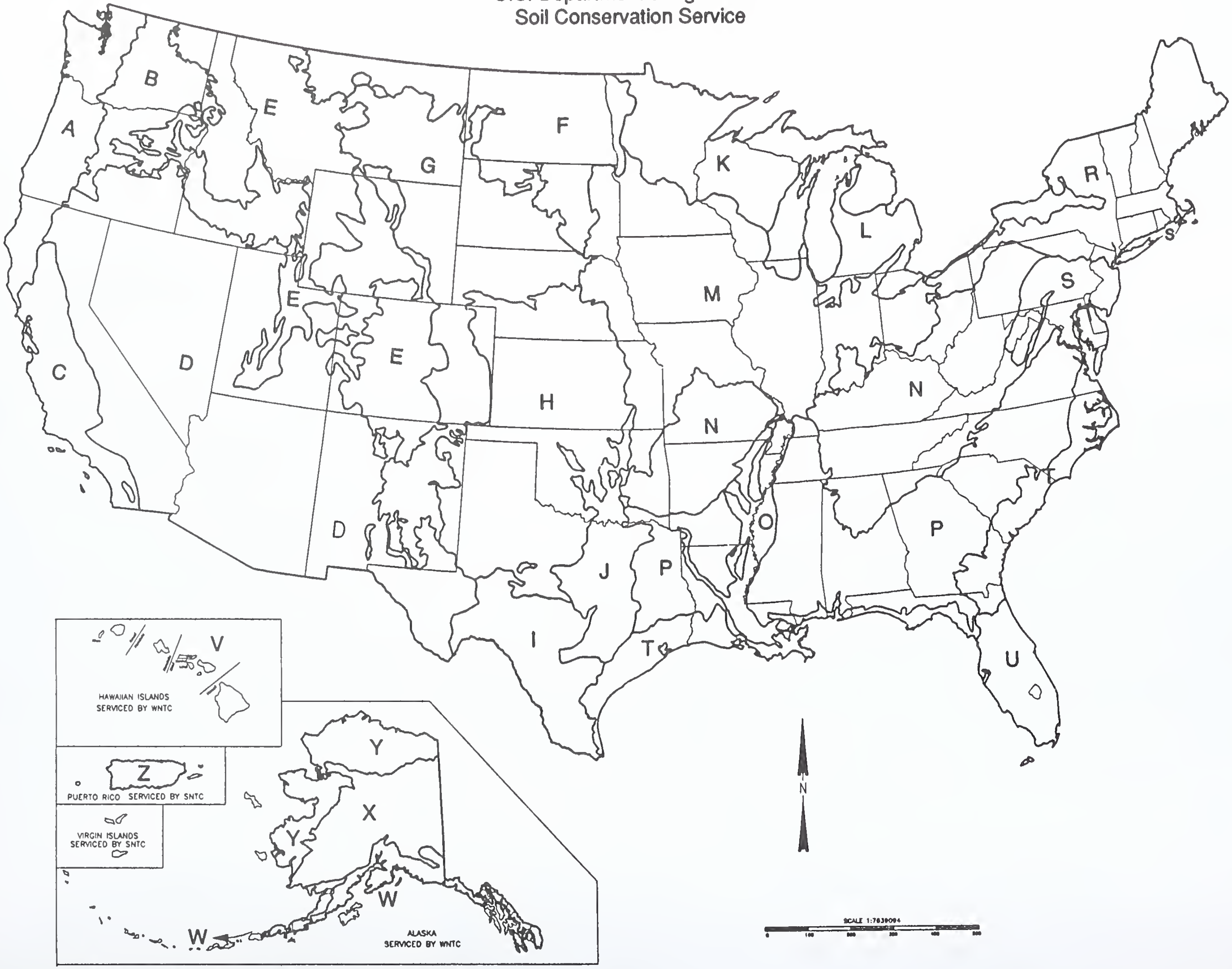

Source: Map prepared using automated map construction. Albers equal area projection. National Cartography and Geographic Information System Center, Fort Worth, Texas 1993.

Resource Regions and Areas
as of January 1984
Land Resource Regions (LRR)

A	NW Forest, Forage and Specialty Crops
B	NW Wheat and Range
C	California Subtropical Fruit, Truck and Specialty Crops
D	W. Range and Irrigated
E	Rocky Mtn. Range and Forest
F	N. Great Plains Spring Wheat
G	W. Great Plains Range and Irrigated
H	C. Great Plains Winter Wheat and Range
I	SW Plateaus and Plains Range and Cotton
J	SW Prairies Cotton and Forage
K	N. Lake State Forest and Forage
L	Lake States Fruit, Truck and Dairy
M	Central Feed Grains and Livestock
N	East and Central Farming and Forest
O	Miss. Delta Cotton and Feed Grains
P	S. Atlantic and Gulf Slope Cash Crops, Forest and Livestock
R	NE Forage and Forest
S	N. Atlantic Slope Diversified Farming
T	Atlantic and Gulf Coast Lowland Forest and Crop
U	Florida Subtropical Fruit, Truck Crop and Range
V	Hawaii
W	S. Alaska
X	Interior Alaska
Y	Arctic and W. Alaska
Z	Caribbean Area

Major Land Resource Areas
(MLRA)
MLRAs and number designation
(see Agriculture Handbook 296)

January 1993 1007614

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Crop Residue Management To Reduce Erosion and Improve Soil Quality

North Central

W.C. Moldenhauer and L.N. Mielke, Editors

Abstract

W.C. Moldenhauer and L.N. Mielke, eds. 1995. Crop Residue Management To Reduce Erosion and Improve Soil Quality: North Central. U.S. Department of Agriculture, Agricultural Research Service, CRR–42, 103 pp.

Leaving crop residue on the soil surface has a number of clear advantages over tillage that leaves the soil surface bare. Most notable is the greatly reduced erosion from wind and water. Other advantages include increased yields from conserved water, lower soil temperatures, increased soil organic matter levels, and in many cases reduced requirements of time, labor, and fuel. Mandated conservation compliance by 1995 is an additional incentive for farmers to adopt crop residue management.

This is one of six regional publications that assemble research results and experiences for use by farmers and their advisers as they consider the factors involved in changing from tillage to a system of crop residue management.

Keywords: Agricultural economics, conservation tillage, crop rotation, farming methods, erosion, mulch tillage, no-tillage, nutrient cycling, pest management, raindrop erosion, ridge tillage, soil compaction, soil conservation, soil erosion, surface residue tillage, sweep tillage, tillage, water conservation, wind erosion

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture over others not mentioned.

This publication reports research involving pesticides. It does not contain recommendations for their use nor does it imply that uses discussed here have been registered. All uses of pesticides must be registered by appropriate state or Federal agencies or both before they can be recommended.

While this book was being produced, the Soil Conservation Service (SCS), referred to throughout, was reorganized as the National Resources Conservation Service. The previous name is retained here for conformity to the five companion books.

Issued November 1995

While supplies last, single copies of this publication may be obtained at no cost from a local Soil Conservation Service District office.

Copies of this publication may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161; telephone (703) 487–4650.

This is one of six regional publications designed to bring research results and experience of experts in the field of crop residue management to the attention of farmers and their advisers. A copy of the five other regional reports on *Crop Residue Management To Reduce Erosion and Improve Soil Quality* can be obtained from the Conservation Technology Information Center, 1220 Potter Drive, Room 170, West Lafayette, IN 47906 (FAX 317–494–5969, telephone 317–494–9555). The other five regions are Appalachia and Northeast, Northwest, Northern Great Plains, Southeast, and Southern Great Plains.

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1 Introduction: Why the Emphasis on Crop Residue Management?

W.C. Moldenhauer and L.N. Mielke

Soil erosion by wind or water degrades our soils. Besides outrightly removing material from the fertile topsoil, large windstorms or rainstorms selectively remove material high in organic matter and nutrients. The result is surface soil depleted of plant-available nutrients, high in density, and low in porosity and capacity for water intake.

Recognizing the rapidity with which U.S. soils are degrading—especially on the 143 million acres of highly erodible lands—Congress passed the Food Security Act in 1985 to conserve our soils and ensure adequate food supplies for future generations. **The act sets a deadline of December 31, 1994, for full implementation of plans to control erosion on highly erodible lands if farmers are to maintain their eligibility for U.S. Department of Agriculture (USDA) program benefits.** When presented with the broad spectrum of available technologies at USDA Soil Conservation Service (SCS) offices, fully three-fourths of farmers concluded that the most cost-effective means for controlling erosion on their highly erodible lands was to keep more crop residues on the soil surface.

Any tillage and planting system that leaves all or some portion of the previous crop's residue on the soil surface is described as crop residue management by SCS and the Conservation Technology Information Center, West Lafayette, IN. Surface residue cover is known to greatly reduce soil erosion, even though the percentage of surface residue required depends on the site and other conservation practices included in a total conservation plan. As residue cover approaches 100 percent, soil erosion approaches 0 percent; with 50 percent residue cover, erosion reduction is about 83 percent; when residue cover is 10 percent, erosion reduction is still about 30 percent compared with clean tillage.

Farmers' willingness to leave residue on the surface was greatly enhanced by the development of herbicides, which provided an alternative to tillage for controlling weeds. Efforts of equipment companies and innovative farmers in developing equipment to leave more residue on the surface and then to plant through it have facilitated the availability and use of crop residue management. The negative effects of crop residue, once looked on as far outweighing the benefits, are now seen as greatly overestimated or solutions have been found to make the negative results manageable. As the scientific, industrial, and farm communities persistently address the problems and find solutions, they approach remaining problems more as challenges than as insurmountable disadvantages. This change of attitude has played a major role in accelerating the acceptance of crop residue management.

This publication is addressed to farmers, extension agents, conservation workers, and others with an interest in reducing soil erosion. It summarizes results of research and experience that show the potential benefits and problems related to decreased tillage and to leaving more residues on the soil surface. In the 17 chapters that follow, experts discuss the equipment, management practices, crop protection chemicals, crop rotations, cover crops, and cropping systems that will enable farmers to control their erosion on their lands, so they are in Federal conservation compliance, while simultaneously optimizing their net returns and improving the environment and natural resources.

This is one of six regional reports. Some of the technology is suited specifically to the climate and soils of particular regions. However, due to recent and rapid development, not all of the potentially useful technologies have been tried in all regions. Consequently, some of the surface residue management technologies used in other regions and discussed in the other five reports may apply to the North Central Region. See the "Abstract" page in the front of the book for information about obtaining the other five reports.

Sources of Additional Information

MidWest Plan Service. 1992. Conservation tillage systems and management: crop residue management with no-till, ridge-till, mulch-till. MidWest Plan Service Handbook 45. Available from the MidWest Plan Service, 122 Davidson Hall, Iowa State University, Ames, IA 50011–3080.

Many conservation tillage farmers have formed clubs, associations, and alliances to exchange information. A list of these groups is available from the Conservation Technology Information Center, 1220 Potter Drive, Room 170, West Lafayette, IN 47906–1383; telephone (317) 494–9555.

2 Terminology

David L. Schertz and John Becherer

In the early 1960's the terms *minimum tillage* and *reduced tillage* were used to denote fewer trips over the field. These fewer trips may or may not have left residue on the soil surface after planting or during the critical wind erosion period. The terms did not quantify the amount of surface residue left or any resulting reduction in erosion. The term *conservation tillage* also became popular. This term did imply that some surface residue was left but initially did not specify an amount.

In 1984, the Soil Conservation Service (SCS) defined *conservation tillage* as follows:

any tillage and planting system in which at least 30 percent of the soil surface is covered by plant residue after planting to reduce soil erosion by water or, where soil erosion by wind is the primary concern, at least 1000 lb/acre of flat small-grain residue equivalent are left on the soil surface during the critical wind erosion period.

The objective of conservation tillage was to leave surface residue that would reduce the eroding forces of rain and wind. This definition remained standard through the early 1990's.

Conservation tillage comprises no-tillage (also called no-till), ridge tillage (ridge till), and mulch tillage (mulch till). They are defined by the Conservation Technology Information Center as follows:

- **No-tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is done in a narrow seedbed or slot made by coulters, row cleaners, disk openers, in-row chisels, or rototillers. Weed control is done primarily with herbicides; cultivation may be used for emergency weed control.

- **Ridge tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is done in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is done with herbicides or cultivation or both. Ridges are rebuilt during cultivation.

- **Mulch till.** The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is done with herbicides or cultivation or both.

These definitions have gained considerable acceptance. Even so, some confusion remains as to the meaning of conservation tillage. Research shows that surface residue of less than 30 percent may reduce erosion considerably even though, by definition, this amount is not considered conservation tillage. Most farmers chose to comply with the provisions of the 1985 Food Security Act to maintain eligibility for USDA program benefits. Many farmers selected conservation tillage practices that left sufficient crop residue on the surface to meet conservation goals. However, some of these selected tillage practices that left less than the amount required to be classified as conservation tillage were combined with other practices to achieve conservation goals. Adding to the confusion was the fact that some people considered conservation tillage to mean only no-till. It became clear that standard terminology was needed to clarify the impacts of leaving all or a portion of the previous crop's residue on the soil surface. The term *crop residue management* evolved to address, among others, the benefits of surface residue in reducing soil erosion.

The practice of crop residue management encompasses an entire cropping year. (1) It begins with planting a crop that will meet a specified residue production goal. Farmers are encouraged to grow cover crops with low-residue cash crops, where applicable. (2) Good distribution of residue at harvest is an essential component. (3) It requires careful planning of the depth, speed, and tools involved in any tillage operation to maintain the desired amount of residue on the surface.

Crop residue management is defined as follows:

Any tillage and planting system that uses no-till, ridge till, mulch till, or other systems designed to retain all or a portion of the previous crop's residue on the soil surface. The portion required depends on other conservation practices that are included in the farmer's total conservation plan.

Throughout this publication, the terms *reduced tillage, minimum tillage, conservation tillage,* and *crop residue management* are used interchangeably. Each term refers to systems that leave all or a portion of the previous crop's residue on the soil surface to reduce soil erosion to an acceptable level.

3 Crops, Climate, and Soils

H. Raymond Sinclair, Jr., William J. Waltman, and Robert D. Nielsen

Large areas of highly productive soils and favorable climate make the 280,110-square-mile North Central Region the most outstanding grain-producing region in the world (U.S. Department of Agriculture 1982). Corn and soybeans make up the largest acreage. Other major crops include winter wheat, alfalfa and other forages, grain sorghum, flax, and oats. Tobacco, cotton, and truck and canning crops are important in some portions of the region.

Soil erosion is a major concern primarily because of sloping soils and intensive rainfall. Much of the area is considered to be highly erodible, and crop residue management systems are used extensively and have become an integral part of conservation plans. Soil erosion from wind can also be a major concern in the far western and southern portions of the region, and crop residue management systems are used in these areas to reduce erosive wind energy. In much of the region, the climate and soils are favorable for earthworms, which can have a significant effect on water infiltration and percolation, thereby reducing surface runoff.

The favorable soils and climate in the central, southern, and eastern portions of the North Central Region have made it possible to manage a substantial number of acres with crop residue systems. No-till soybeans following corn are fast becoming the norm. While mulch till accounts for the largest percentage of acres managed with crop residue systems, no-till acreage has increased in the past 5 years and seems to be outpacing other forms of crop residue management.

In the northern part of the region, crop residue management systems are less commonly used, primarily because of colder soil temperatures. However, with the introduction of improved planting equipment and row-cleaning devices, colder soils in the spring are presenting less of a concern and crop residue management is apt to make more inroads in this area. Where soils stay cooler in the spring because of cold winter temperatures or slow internal drainage, farmers know the importance of moving residue off the row to be planted.

In areas where low-residue crops are grown on sloping soils, cover crops are often used to provide additional residue cover, especially in the southern portion of the region where precipitation is less limited than it is in the northern areas. Where precipitation decreases, cover crops are less popular because in early spring they remove soil moisture that the planned crop might otherwise utilize. Where precipitation is more plentiful, removal of early spring moisture by cover crops is not a concern and may allow earlier planting of the cash crop or otherwise help to increase yields. Cover crops and double cropping are much more likely to provide net benefits in the warmer, moister areas of the region.

Soils of the region were formed in sandy, loamy, silty, and clayey sediments and residuum that weathered from bedrock under native prairie grass and hardwood forest vegetation. The dark-colored soils formed under native prairie vegetation and have about 3–9 percent organic matter in their surface layers. The light-colored soils formed under native hardwood forest vegetation and have less than 3 percent organic matter in their surface layers. Soils with surface layers low in organic matter are more erodible than soils with surface layers high in organic matter, when all other soil properties are similar.

The topography ranges from level to rolling to steep or very steep. Most of the region was influenced by glaciers except for Missouri, Oklahoma, a portion of Kansas, and the so-called “driftless” area of Illinois, Iowa, Minnesota, and Wisconsin. See table 1 for more specific information about the soils.

Precipitation ranges from 19 inches in the northwest to 48 inches along the eastern and southern fringes. The entire region experiences periodic droughts, with the frequency increasing from east to west.

The frost-free period ranges from 127 days along the northern fringe to 217 days in the extreme southwest. Most of the North Central Region has snow and frozen soils. These diminish from north to south. See table 2 for more detail about the climate.

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Table 1. Major Land Resource Areas, number of acres, and soil characteristics of the North Central Region

Major Land Resource Area*	Acres (in millions)		Parent material	Texture		Wetness	Typical cropland slopes
	Total	Cropland†		Surface	Subsoil		
102A Rolling Till Prairie	9.2	5.0	Till	Loamy	Loamy	Slight–severe	0–9
102B Loess Uplands and Till Plains	10.8	7.0	Till Alluvium Loess	Loamy Clayey Silty	Loamy Clayey Silty	Slight–severe	0–17
103 Central Iowa and Minnesota Till Prairies	17.7	13.4	Till Lacustrine	Loamy Silty	Loamy Silty	Moderate–severe	0–18
104 Eastern Iowa and Minnesota Till Prairies	5.9	4.3	Till Alluvium Lacustrine	Loamy	Loamy	Slight–severe	0–18
105 Northern Mississippi Valley Loess Hills	12.0	3.7	Residuum Colluvium Alluvium Outwash Loess	Loamy Silty Sandy	Loamy Clayey Silty Sandy	None–moderate	0–20
106 Nebraska and Kansas Loess-Drift Hills	6.6	3.4	Till Loess Alluvium	Loamy Silty Clayey	Loamy Silty Clayey	Slight–severe	0–20
107 Iowa and Missouri Deep Loess Hills	13.0	8.3	Loess Alluvium Till	Silty Clayey	Silty Clayey Loamy	None–severe	0–20
108 Illinois and Iowa Deep Loess Hills	20.9	14.8	Loess Alluvium Till Lacustrine	Silty Clayey Loamy	Silty Clayey Loamy	None–severe	0–20
109 Iowa and Missouri Heavy Till Plain	8.6	2.8	Loess Till Alluvium	Silty Loamy Clayey	Silty Loamy Clayey	Moderate–severe	0–14

Table 1.—Continued

Major Land Resource Area*	Acres (in millions)		Parent material	Texture		Wetness	Typical cropland slopes
	Total	Cropland†		Surface	Subsoil		
110 Northern Illinois and Indiana Heavy Till Plain	6.4	4.3	Till Loess Outwash Lacustrine	Loamy Silty Sandy Clayey	Loamy Silty	None–severe	0–18
111 Indiana and Ohio Till Plain	21.6	13.8	Till Loess Outwash Lacustrine Organic	Loamy Silty Muck	Loamy Silty Sandy Muck Peat	None–severe	0–18
112 Cherokee Prairies	14.8	3.8	Residuum Alluvium Loess	Loamy Silty	Clayey Silty Loamy	Slight–severe	0–8
113 Central Claypan Areas	6.6	3.8	Loess Till Alluvium	Silty Loamy Clayey	Silty Loamy Clayey	Moderate–severe	0–18
114 Southern Illinois and Indiana Thin Loess and Till Plain	7.7	3.9	Loess Till Residuum Alluvium	Silty Loamy	Silty Loamy	Moderate–severe	0–18
115 Central Mississippi Valley Wooded Slopes	17.5	7.7	Loess Alluvium Till	Silty Clayey Loamy Sandy	Silty Clayey Loamy Sandy	None–severe	0–18

* See map inside back cover to find MLRA locations.

† Crops include corn, soybeans, wheat, alfalfa and other forage in rotations, flax, oats, tobacco, cotton, and truck and canning crops. Crops do not include fruit, nuts, vineyard, bush fruit, berries, and other such plants.

Source: Galloway et al. 1981; U.S. Department of Agriculture 1992b, 1994

Table 2. Climate parameters in the Central Feed Grains and Livestock Region (Land Resource Region M) based on 1961–90 normals

Major Land Resource Area[*]	Mean annual air temperature (°F)	Mean annual precipitation (inches)	Frost-free period[†] (days)	Growing degree days[‡] (heat units)	Soil temperature regime
102A Rolling Till Prairie	40–44	19–28	127–151	2201–2800	100% frigid[§]
102B Loess Uplands and Till Plains	43–50	22–30	136–160	2401–3600	88% mesic[‖], 12% frigid
103 Central Iowa and Minnesota Till Prairies	43–48	24–34	141–160	2401–3200	51% mesic, 49% frigid
104 Eastern Iowa and Minnesota Till Prairies	43–48	30–36	136–159	2401–3200	33% mesic, 67% frigid
105 Northern Mississippi Valley Loess Hills	42–48	29–35	126–165	2201–3200	34% mesic, 66% frigid
106 Nebraska and Kansas Loess-Drift Hills	49–55	28–38	156–185	3201–4400	100% mesic
107 Iowa and Missouri Deep Loess Hills	44–54	26–40	146–190	2601–4200	99% mesic, 1% frigid
108 Illinois and Iowa Deep Loess Hills	46–53	33–40	152–182	2601–4000	100% mesic
109 Iowa and Missouri Heavy Till Plain	48–53	34–39	158–182	2801–4000	100% mesic
110 Northern Illinois and Indiana Heavy Till Plain	46–51	32–39	155–174	2201–3600	100% mesicTill Plain
111 Indiana and Ohio Till Plain	47–53	31–43	150–181	2401–3800	100% mesic
112 Cherokee Prairies	53–61	35–44	174–217	3601–5200	65% mesic, 35 thermic[¶]
113 Central Claypan Areas	51–55	36–44	165–194	3001–4200	100% mesic
114 Southern Illinois and Indiana Thin Loess and Till Plain	48–56	38–45	157–192	2601–4400	100% mesic
115 Central Mississippi Valley Wooded Slopes	49–57	35–48	166–198	3001–4400	98% mesic, 2% thermic

[*] See map inside back cover to find MLRA locations.
[†] Based on consecutive days of a greater than 32 °F threshold.
[‡] Base temperature threshold = 50 °F.
[§] Frigid = soil temperature of less than 47 °F.
[‖] Mesic = soil temperature ranging from 47 to 59 °F.
[¶] Thermic = soil temperature ranging from 59 to 72 °F.

Source: Loveland 1991; U.S. Department of Agriculture 1992a; U.S. Department of Commerce 1992

4 Conservation Tillage Systems Used in the North Central Region

Daniel McCain and John Becherer

Systems in Use

No-Till

No-till as a practice for the midwestern crops of corn and soybeans is increasing at a phenomenal rate. Since the late 1980's, growth in the use of the technique has exceeded expectations. In 1989 no-till was used in the United States on 5.06 percent of the total planted acres (including 7.14 percent of those in corn and 3.96 percent of those in full-season soybeans). By 1994 no-till usage had more than tripled to include 16.5 percent of all planted acres (including 17.8 percent of those in corn and 26.0 percent of those in full-season soybeans) (table 3).

Ridge Till

North Central acres in ridge till also are also increasing. One generally finds the practice of ridge till confined to growth areas in the western Corn Belt. Narrow-row soybean planting technology has cut into the advance of ridge till in states that predominately raise corn and soybeans in rotation. Where continuous corn is common and furrow irrigation is very compatible with ridge till, use of ridge till is increasing rapidly.

Mulch Till

Mulch till has had a flat growth trend in the 1990's, perhaps due to technological advances and the mechanical advantages of no till. Today farmers are searching for efficiencies that take them beyond the near-conventional attributes of mulch till. Many compliance plans for highly erodible lands could be accomplished using mulch-till, but achieving a 30–50 percent residue cover with full-width tillage operations can be difficult for farmers with old habits.

Other

Use of other types of tillage that leave less than 30 percent residue is steady to decreasing, depending on the location in the region. Some farmers are making abrupt changes in tillage choices, such as moving from plow tillage to no-tillage. In fact the majority of acreage that farmers are newly leaving in the highest residue levels had been managed with low-residue tillage.

Advantages and Disadvantages of the Systems

No-Till

Pros. Using a no-till system saves energy, time, labor, and machinery. Compared with conventional tillage, no-till can cut fuel usage by 65 percent or more. A farmer can reduce the number of trips across the field to two in the spring—one to apply herbicides and one to plant. And fewer trips reduce labor and maintenance costs.

Farmers who switch to no-till often diversify their operations or expand their acreage since they have more time available. A no-till farmer needs only three pieces of equipment—a tractor, a no-till planter or drill, and a sprayer. The up-front investment in quality equipment may seem high; however, in the long haul the efficiency and less costly maintenance is key to attracting no-till advocates.

No-till fields attract and support a variety of wildlife and earthworms. A high level of erosion control is possible in these fields, since the soil is undisturbed from harvest to planting. The quantities of crop residue left on the surface greatly reduce the contamination of streams and rivers from runoff.

Cons. It is now almost too easy to jump into a no-till operation. The pitfall of no-till is that it requires careful advance planning and a change in mindset. No-till requires good management and strict attention to detail with weed control, application of chemicals, planting, and distribution of residue at harvest.

The types of herbicides used in no-till—burndown, residual, or early preplant—are usually more costly than the preplant-incorporated herbicides used in other systems. Residual and early preplant herbicides fail if rainfall does not activate them. If excessive rainfall delays planting, then there's the risk of the herbicide not lasting through the season.

Ridge Till

Pros. To preserve residue and reduce input costs, some farmers are turning to ridge tillage. With this system farmers use sweeps, discs, coulters, or row cleaners to plant the crop in a seedbed prepared on ridges. The ridges are then rebuilt and maintained with cultivation as the crop grows. Crop residue covers the soil between harvest and planting, protects it from wind and water erosion, and preserves soil moisture. The ridges allow the soil to warm earlier. These benefits make ridge tillage an appropriate choice for soils that normally remain too wet for spring tillage.

Farmers who use ridge tillage typically band herbicide over the rows for weed control, which reduces the amount of chemical needed. Cultivation removes weeds in the row centers. Ridge tillage is the natural choice in areas that employ furrow irrigation, since irrigation and conservation tillage use identical equipment to build ridges.

Cons. For farmers already set up to farm on ridges, ridge tillage is economical and effective, but for farmers who are just getting started the system requires special equipment. The planter must be equipped with row-cleaning devices. Planting stabilizer attachments should be added to keep the planter properly centered on top of the peaked ridges, and a special ridge cultivator is required to properly build and maintain ridges.

An easy mistake to make with ridge tillage is operating the ridge-cleaning devices too deeply. The devices should clean the ridges of crop residue and weed seeds but remove very little soil. Taking too much soil extracts the root masses and throws them into the row middles. If the soil is heavy, it may be very moist within the ridge at planting time, and too much taken off the top will present poor planting conditions.

Mulch Till

Pros. This form of full-width noninversion tillage is the most common type of conservation tillage. The challenge with this technique is to use the proper equipment and settings (speed, depth, time of operation) to achieve the desired residue level after planting. Mulch tillage allows use of economical preplant-incorporated herbicides and incorporation of fertilizers. Measuring residue before and after each tillage pass, however, is an important step in meeting after-planting residue goals. New tillage and finishing tools are now available that can help the grower preserve even higher levels of residue than were previously possible in a mulch-till system. Sweeps and rolling-tine devices, for example, can actually uncover previously buried residue in worked ground.

Cons. If the primary goal is to maintain a high level of crop residue, mulch tillage may not be the optimal system, particularly in a rotation where residue from the previous year's crop is fragile, such as soybean residue. But even planting into nonfragile residue like corn stubble requires careful planning to maintain more than 30 percent coverage.

A considerable amount of mulch-tilled cropland starts with adequate residue and later ends with marginal levels. Events that can affect residue amounts include droughts, wet seasons, or too many trips over the field to incorporate chemicals.

Most potential problems with any of the aforementioned tillage types can be eliminated with knowledge and experience, careful planning, and advances in equipment, chemicals, plant varieties, and technology.

Table 3. Management systems used in the 12 Midwestern states, 1994 (in percentages)

	Conservation tillage				Other tillage practices	
	> 30 Percent residue or 1,000 lb SGE*				15-30% Residue	< 15% Residue
Crop	No-till	Ridge till	Mulch till	Total conservation tillage	500-1,000 lb SGE	< 500 lb SGE
Corn, full season	17.8	3.5	19.3	40.6	23.7	35.8
Corn, double cropped	29.6	NA†	6.3	35.9	5.5	58.5
Small grain, spring seeded	4.8	NA	27.9	32.7	35.8	31.5
Small grain, fall seeded	9.2	0.05	21.6	30.8	34.4	34.7
Soybeans, full season	26.0	1.4	23.1	50.5	23.5	26.0
Soybeans, double cropped	64.0	0.4	9.1	73.5	12.6	14.0
Cotton	0.6	3.1	0.2	3.9	1.9	94.2
Grain sorghum, full season	13.6	2.3	25.8	41.7	30.7	27.6
Grain sorghum, double cropped	34.0	1.9	21.2	57.1	20.9	22.0
Forage crops	8.5	NA	14.4	22.9	24.8	52.4
Other crops	4.0	0.2	15.0	19.2	26.6	54.1
Total planted	16.5	1.7	21.4	39.6	27.8	33.6

* SGE = small-grain equivalent.

† NA = not applicable.

5 Making the Transition From Clean Tillage to Crop Residue Management

Dwayne Beck

Because each situation is unique, only the producer can decide whether to make operational changes and when and how to make them. Making the transition from a farming system based on intensive tillage to one where substantial amounts of residue are left on the soil surface involves a great deal of thought. This chapter outlines some important factors that need to be considered before and during such a transition.

Any successful farming operation is a complex system. It is not possible to change one component of the system without affecting others. Changing from low-residue to high-residue farming simply by altering the amount or type of tillage is somewhat like changing from gasoline to diesel power by pumping the gas out and filling the tank with diesel. The choice to leave more crop residues on the soil surface entails substantial modifications to the present system or development of an entirely new one. If these changes are not made, the system will either fail to yield the desired results or, worse, cause management difficulties.

The best approach to a transition is to review the current mode of operation. Why does the producer do things a certain way while neighbors operate differently? What is good or bad about the present system?

The next step is to study successful and unsuccessful crop residue systems in the immediate area and other areas and assess what makes the successful systems work and the poor ones fail. One should resist outright adoption of someone else's system; what may work for one producer may fail for another.

Because mistakes are costly, it is important to obtain as much professional advice and information as possible by reading and attending meetings and field days. There is no single recipe that can guide all producers in making a successful transition to conservation tillage. However, there are some broad categories that should be considered when deciding how to make the transition.

Economic Considerations

Making an economically successful change to conservation tillage depends on producers' ability to take risks, how thoroughly they studied and planned, their labor situation, their machinery, and whether the land is highly erodible. With sufficient planning, a producer can design a system that improves upon the one he or she has been using. Once this is done, the quicker the change can be made the better. A quick change limits the time the producer owns two sets of equipment, enables the producer to take advantage of the new system more quickly, and will probably return a better trade-in value on unneeded equipment. A quick changeover does carry more financial risk, particularly if a producer is not prepared agronomically, economically, or psychologically.

Some producers choose to switch quickly because their land is highly erodible and they face substantial financial loss if they do not adopt conservation practices. In such cases the financial risks associated with noncompliance may outweigh the risks of rapid change. Others may need to trade equipment and hope to reduce these costs. Other producers may face hiring additional laborers if they continue to use tillage extensively, so they switch to conservation tillage to avoid the expense and time of training new hires. Still others may wish to devote more time to other enterprises.

Producers are more likely to engage in a slower transition if they lack sufficient guiding research or experience to design the agronomic aspects of the system without some field testing. Those who take a slower approach usually rent the appropriate equipment or hire custom operators who own the equipment to try conservation tillage on a limited number of acres. If testing is an option, some parcels of land should be continuously treated with reduced tillage rather than applying the technique to different parcels each year. The primary economic advantages of the slow approach are twofold: (1) the reduction of risks associated with poor agronomic planning and (2) the opportunity for evaluating machinery before purchases are made. While reliance on custom work and rented machinery reduces risk, it generally increases costs. Many of the other economic advantages of reduced tillage—such as more diversity in rotations, spreading seeding and harvesting operations over a longer time, and lower horsepower requirements—do not become apparent when the evaluation is conducted on a small acreage.

Moving slowly allows not only the producer but also any partner, landlord, or banker to acquire some confidence that their investment is safe with conservation tillage, as well as to win the partner or landlord's always necessary approval.

Most producers making the transition from conventional tillage to no-till systems take an approach between the "all at once" and "go slow" approaches. They quickly adopt a relatively low-investment, low-risk system. As soon as they acquire some experience with their new system, they begin to evaluate ways to fine-tune and change that system and to make it more cost effective. This middle-of-the-road approach is very similar to what most farmers do with their present practices, which are constantly being modified in an attempt to make them better.

Agronomic Conditions

Many published data on the agronomic aspects of conservation tillage appear to be contradictory. The key to making sense of such apparent discrepancies is to identify the different circumstances in the trials and why they caused the results they did.

An example illustrates the importance of careful analysis. Two comparative tillage studies were conducted in central South Dakota. The first study showed that conventional tillage produced greater returns than no-till or minimum tillage. In the second study no-till returns were higher than minimum-till returns, and minimum-till returns were higher than conventional-till returns. Several differences in management techniques contributed to the results. The most important was probably crop rotation. The first study used winter wheat-fallow and continuous wheat with all three tillage methods. The second study used wheat-soybean and wheat-corn-soybean rotations.

Both studies took place in an area that averages 18.5 inches of precipitation annually. The rotations in the first study led to significant losses from disease and problems with weeds when tillage was reduced or eliminated. Even if these losses could have been controlled, wheat does not need the increased moisture that results from reduced tillage, except in drier-than-normal years. The more diverse rotations of the second study limited disease and weed pressure, which resulted in reduced production costs, and the rotations used high-water-use crops that took full advantage of the moisture saved from conservation tillage.

So, the most appropriate tillage method depends on the rotation used, and the most appropriate rotation depends on the management system used. The seemingly conflicting results actually make perfect sense when these interactions are understood. A good comparison in these studies is between the best conventional tillage system (wheat-fallow) and the best no-till system (wheat-corn-soybeans). A producer, then, is well advised to compare the present system against a system of less tillage that allows more intense rotations.

Several considerations—crop rotation, competition, and sanitation—gain importance once tillage is reduced. Almost all of the management problems associated with reduced tillage can be traced directly to a failure in one of these categories.

Crop Rotation

Until recently proper crop rotation was the cornerstone of agriculture. Now intensive tillage in conjunction with modern technology enables producers to move more toward monocrop (single-crop) and two-crop rotations than they could less than 20 years ago. Most producers are somewhat aware of the benefits of crop rotation in limiting disease, weed, and insect pressure, but many lack experience in properly applying the concept to maximum advantage. Proper rotation can prevent most pest problems from getting out of hand and significantly reduce reliance on chemical control. A well-managed no-till system with proper rotation uses less pesticides than does conventional tillage with improper rotation. On the other hand, a no-till or another high-residue system with a poor rotation will usually require more chemical inputs than the same rotation managed conventionally.

There are other benefits of good rotation that are less understood and probably underused. These include improved workload spreading, the potential to better manage water resources, and leaving a better seedbed environment for the succeeding crop.

Workload spreading. In a monocropping system, all harvesting should be done within the short time periods that are optimum for that crop. When there are two or more crops in a rotation system, optimum times for harvesting the different crops generally occur at different times and the harvesting workload is spread over a longer time. Rotations commonly result in this workload spreading for other labor-intensive seasons, such as planting and weed control, and generally enable the farmer to hire less seasonal labor and to reduce the number or size of tractors and equipment needed. Having fewer acres of each crop in rotation also enables the producer to conduct essential operations closer to the optimum time for each crop.

Better management of water. Producers who irrigate their crops or who farm in areas with adequate or surplus moisture are able to concentrate on a smaller number of high-value crops in their rotations. In drier areas there is a need for additional drought-tolerant crops, which can generally provide reasonably good yields even when soil-water content is low at seeding time. However, rotations facilitate better management of water resources in both humid and arid regions.

Reduced tillage saves water by enhancing its entry into the soil and reducing evaporation. This saving of water can be either good or bad, depending on whether the increased moisture is put to use or allowed to become a management problem. Soil, depending on type, can hold about 1.0–2.5 inches of available water per foot of depth before the water begins to drain away. The ideal condition is to have the root zone fully recharged but not overly full when the crop begins to use water. When soil can no longer hold additional water, problems can occur such as leaching, denitrification, runoff, diseases, and lack of trafficability. A proper rotation—one designed for the tillage system used—makes good use of available water. That is why the match between certain rotations and conventional tillage has been successful and popular. Because additional soil water is saved with reduced tillage, the frequency of years that are too wet will increase unless the rotations are more intense, that is, unless they use more water. Without a change in rotations, reduced tillage will only show production advantages in drier-than-normal years and may result in decreased productivity in wet years.

Cropping intensity and more complete use of water can be increased by introducing more full-season crops into rotations and eliminating fallow or by substituting a nitrogen-fixing cover crop in lieu of fallow. In more humid regions where rotations are already heavily dominated by full-season crops and conventional tillage, the options include double cropping or the use of cool-season cover crops between full-season crops.

The example that follows illustrates how rotations can be designed to accommodate weather conditions and make good use of water. A no-till producer who wishes to grow corn in eastern North Dakota or northeastern South Dakota is less concerned with a lack of soil moisture and is more limited by soil temperatures than a producer is in central South Dakota, who is more concerned with moisture than with lack of heat. The first producer would probably plant much of his or her corn following low-residue crops such as soybeans, which produce a warmer, drier seedbed. The producer in the drier area would plant corn behind a higher residue crop, such as a small grain, whose residues, when left on the soil surface, maximize moisture storage .

Where weather is highly variable from year to year, as is common on the Great Plains or even on the western edge of the North Central Region, it is usually wise to include some rotational sequences that do well in untypical years. When soils are very dry, producers may plant some corn following wheat to provide some protection. However, if the weather turns cool and wet, this corn may not mature properly. The second farmer may plant corn following soybeans or sunflowers on limited acreage; these would produce well in a wet year and could be used for forage in a dry year.

Seedbed environment. Another aspect of rotation that needs careful study when adopting conservation tillage is the ability of each crop to provide a good seedbed for the crop that follows. The main reasons cited for continued use of tillage are to control weeds and to create a favorable environment for crop growth. When tillage is significantly reduced or eliminated, a good share of these jobs must be handed over to a well-planned rotation. Designing such a rotation requires the producer to have a good understanding of the climate, the soils, and the conditions each crop prefers. With conventional tillage it is common practice to seed wheat following corn. This rotation does not work well in high-residue systems, since the amount and type of residue left by corn hinders proper seed placement and early growth of wheat and can lead to severe head scab infections during flowering.

To give another example, using conventional tillage, a producer in a wet, cool area plants corn following wheat, which had been fall plowed. This system works since sufficient moisture had accumulated between harvesting the wheat and planting the corn that the waste of water caused by plowing could be tolerated. The producer ends up with a warm, moist seedbed and a soil profile that is full of moisture most years. However, if the producer had seeded corn behind soybeans using conventional tillage, the corn often would have suffered from lack of moisture later in the growing season due to the water wasted by plowing. No-till corn following soybeans would work well in this scenario most years because water is not wasted or its waste is substantially reduced.

Sanitation

Sanitation refers to any practice that prevents weeds, diseases, or insects from being introduced or established. Sanitary practices include using weed-free seed, cleaning equipment between fields, eliminating perennial and noxious weeds by spot treatment before they spread, controlling volunteer grain and weeds to prevent insects from laying eggs, and, as much as possible, preventing weeds from going to seed. Sanitation also includes some practices more commonly associated with conservation tillage, such as mowing along field borders and waterways before grass produces seed or at least before using the combine (which can gather the seeds and spread them 30 ft into the field).

Competition

Plants rely heavily on their competitive abilities to survive. Any measures the producer can take to create an environment that gives the crop an advantage will significantly reduce the ability of weeds to compete. Examples include planting good seed, using sound fertility practices, and using well-adapted crop varieties. Some practices that may help crops compete in a reduced tillage system are listed following:

- using starter or “pop-up” fertilizers to assure a fast start,
- using seeding equipment with superior depth-control capabilities to assure uniform stands,
- increasing seeding rates and planting rows as close together as possible to develop an early plant canopy,
- designing proper rotations to create an environment that favors the crop, and

- most importantly, uniformly spreading chaff and crop residues at harvesting time. This last practice is extremely important (see chapter 6).

Most of the agronomic concepts for conservation tillage discussed here are not greatly different from those used with conventional tillage. The difference is that the systems are dissimilar. Some of the old limiting factors associated with conventional tillage (such as lack of soil moisture) become less dominant with reduced-tillage systems, and some new limiting factors take their place. The secret is for the producer to design agronomic components that allow him or her to take advantage of the strengths and minimize the weaknesses of high-residue systems.

Psychological Considerations

Some producers relish the challenge of making changes in their operations. Others plan changes for the sole purpose of improving the bottom line; they do not necessarily enjoy the process but hope to enjoy the results. Still others choose not to make any changes in their operations until it becomes clear that change is necessary to survive. Most producers fall somewhere in between these categories. In considering a change, producers should not feel pressured by what the neighbors are doing or by information in the farm press but instead should adopt what will work for their operation.

Producers should expend the effort required and gain the knowledge necessary to make the transition successfully. Problems are inevitable, and producers should remember that some component introduced to the system has caused the problem—not the system itself. As a rule, managers who are successful conventional tillage farmers will probably be even more successful conservation tillage farmers.

P.S. If you decide not to trade the plow or disk and instead to park it in the trees, be sure to take off the tires, because grandpa may till all the stubble fields while you're on vacation.

6 Managing Crop Residue From Harvest to Planting

Peter B. Hill

Ideally, a producer's crop residue management strategy begins at harvest with proper distribution of crop residue behind the combine. It continues with subsequent measurements of residue cover after fall or spring tillage operations and finishes with measurements after planting to ensure that desired levels are achieved. Between harvesting and planting operations, however, a large portion of residue cover is lost from overwintering or burial by tillage equipment. Because overwintering losses are nearly impossible to control, producers' strategies typically concentrate on managing tillage practices to maintain high levels of crop residue cover.

This chapter focuses on several components of crop residue management: (1) initial characteristics and quantity of residue after harvest, (2) combine adjustments and accessories, (3) decomposition rates, and (4) tillage tools, planter accessories, and adjustments. Other considerations are also discussed.

Crop Residue After Harvest—Initial Characteristics and Quantity

As mentioned, the producer's crop residue management strategy begins at harvest. The amount of residue that remains behind a combine depends primarily on the type of crop, the crop yield, and the row spacing. Figure 1 shows the relationship between dry matter production and percentage of residue cover when the cover is evenly distributed.

Most producers will not know how much dry matter a crop produces, but they will almost always know the per-acre yield. General conversion factors are listed below and can be applied to figure 1:

Crop	lb Residue/bu yield
Wheat	100
Barley	80
Oats	55
Rye	80
Soybeans	50
Corn	60
Sorghum	60

For example, a 40-bu/acre wheat yield leaves about 4,000 lb/acre of straw and chaff. This yield results in about 90–95 percent residue cover (see fig. 1). A 125-bu/acre corn yield results in 95 percent or more residue cover. Obviously, yield-limiting factors such as drought and insect and disease infestations can seriously reduce the amount of cover after harvest.

Typically, there is little or no difference in the residue cover remaining among varieties within a crop. Even among soybeans, where indeterminate varieties produce more dry matter than determinate varieties, there is little difference in residue cover. In corn there are significant differences in biomass production among varieties, especially when silage-type varieties are considered. However, when evaluating varieties for grain production, there is little difference in residue cover remaining after harvest when yields exceed 100 bu/acre (6,000 lb residue/acre) (see fig. 1).

Combine Adjustments and Accessories

Combines that are adjusted improperly can have a dramatic effect on a producer's conservation tillage system. While overlooked by most producers, the combine and its ability to evenly spread residues are the foundation of a producer's crop residue management strategy. The potential for problems with combine residue distribution has increased over the past few decades. Two of the most significant reasons are wider combine headers and higher residue production from new crop varieties.

The most common mistake made in the harvesting operation is to allow crop residue to collect in windrows behind the combine. This accumulation causes the soil under the windrows to stay wetter and cooler longer into the spring. In most conservation tillage systems, planting into windrows results in uneven stands, as the planted seed takes longer to germinate and grow. Uneven no-till corn stands in the North Central Region have sometimes contributed to significant yield reductions. In the Pacific Northwest, negative effects of heavy straw and chaff rows have been observed even where the moldboard plow is used. Other reported problems associated with improper combine residue distribution include the following:

- unsatisfactory weed control from herbicide interception,
- poor performance of planters and tillage implements,
- increased demands on planter equipment,
- poor seed-to-soil contact (from "hairpinning" of residue into the seed row, for example),
- excessive residue lying directly over the seed furrow (allelopathic effects),
- increased pest infestation (for example, from insects and rodents),
- increased weed seed concentration, and

- poor plant nutrient uptake (from fertilizer tie-up or interception).

These problems are usually associated with small grains, such as wheat, but the effects of concentration of residues by a combine can be a problem with almost any crop. For example, combines with large corn heads or bean heads but without a chopper or a spreader can create heavy windrows of residue. In the North Central Region, many producers remove the chopper or spreader when weed populations become too large to easily pass through the combine.

As with other types of equipment, the type of combine used—rotary or cylinder—has little influence on residue cover when adjusted properly. Producers should check residue distribution patterns of newly purchased combines, whether used or delivered new from the factory or dealership.

The widths of typical combine headers have increased from about 12 ft in the early 1950's to more than 20 ft today; combines with header widths of 30 ft or more are also available. Without special attachments or modifications, most standard combines with these header widths are not adequately equipped to spread the larger volumes of residue uniformly. Consequently, a wide variety of attachments are available to help producers manage crop residues more effectively.

Most combines are equipped with straw choppers, which consist of long, angular deflector blades that, when used with high rotational speeds, spread residue over a large area. Some combines offer a straw spreader in place of the chopper. Spreaders use rotating blades or rubber batts to throw or deflect large pieces of crop residue. While the spreader typically distributes the residue more uniformly than the chopper, the chopper can provide more cover, since it chops the residue into small pieces before spreading. The spreader attachment, by design, spreads whole pieces of residue (soybean stems, wheat straw, partial corn stalks) and consequently does not cover as much of the surface.

Another combine attachment that is effective in handling fine materials— primarily from the harvest of small grains or soybeans—is the chaff spreader. Chaff makes up nearly half of the harvested material and does not usually reach the straw spreader or straw chopper because it drops to the ground from the combine sieves. Obviously, with high-yielding crops or crops that have high biomass production, the potential for creating heavy windrows is great. Chaff is easily spread, but because it is lightweight, it is difficult to spread it beyond 20–25 ft using chaff spreaders.

There are a variety of chaff-spreading attachments. The most commonly used ones are hydraulically driven single or dual spinning disks that have rubber batts attached. Like straw spreaders, many are commercially available (many resourceful producers have manufactured their own). Producers find the return on their investment is quite high; the benefits of even residue distribution are many, while the effect of improper distribution is almost always a significant reduction in yield. Generally, single-disk spreaders are more effective for headers under 20 ft, while dual spreaders are more effective for wider headers.

When considering combine attachments, producers should be careful to not overcorrect the problem of windrowing. For example, spreaders may be set to spread the crop material too far, which can create windrows outside the harvested swath. Proper harvesting methods will result in maximum erosion control and seedbeds ideal for planting with conservation tillage systems.

Decomposition Rates Over the Winter

Decomposition of crop residue over the winter months is a function of several factors, including rainfall, temperature, and prior disturbance. Decomposition differs between fragile and nonfragile crops. Nonfragile crops like corn usually have large leaves or stalks or like wheat they produce large quantities of biomass. Fragile and nonfragile crops are listed following:

Nonfragile	**Fragile**
Alfalfa or legume hay	Canola/rapeseed
Barley	Dry beans
Buckwheat	Dry peas
Corn (grain, forage, silage)	Fall-seeded cover crops
Grass hay	Mint
Millet	Potatoes
Oats*	Soybeans
Pasture	Sugar beets
Popcorn	Sunflowers
Rye*	Most vegetables
Sorghum	
Tobacco	
Triticale*	
Wheat*	

* The residue of this crop should be considered fragile if a combine is used with a straw chopper or otherwise cuts straw into small pieces.

At the end of table 4, the effects of overwintering are summarized in terms of the percentage of residue remaining. The percentage is lower for summer-harvested crops such as winter wheat because the residue has more time to decompose.

If crop residue is disturbed by fall tillage or by knifing in fertilizer applications, the decomposition rates will likely be higher than if left undisturbed. This increase results from the residue's being partially buried and broken into smaller pieces, which exposes more surface area and quickens degradation. A combine's straw chopper will also increase the decomposition of small-grain residue by chopping it into small pieces.

Decomposition proceeds quickly when temperatures are above 50 °F and adequate moisture is available. As table 4 suggests, residue cover losses can be as high as 35 percent for fragile crops and 30 percent for nonfragile crops. Even when air temperatures drop below freezing, snow can actually act as an insulating cover and allow decomposition to continue.

Seedbed Preparation—Tillage, Planter Accessories, and Attachments

Strategies for effective crop residue management almost always include some form of conservation tillage. Conservation tillage is any tillage and planting system in which at least 30 percent of the soil surface is covered by plant residue after planting. While present, this amount of cover reduces soil erosion rates by nearly 65 percent from those occurring under a moldboard plow system (0 percent surface cover). A large number of systems, including chisel plow, disk, ridge till, and no-till, have the potential for leaving 30 percent residue cover following corn, grain sorghum, small grains, and in some cases, soybeans. But any system, including no-till, if not properly managed, can leave significantly less residue cover after planting. The tillage and planter/drill-related factors discussed next greatly influence residue cover and should be considered by producers when planning to meet crop residue management goals.

Number of Trips Across the Field

Producers must limit the number and intensity of field operations when aiming to reach crop residue management goals. Table 4 lists types of field equipment, their effects on nonfragile and fragile residues, and the percentage of residue cover after one pass. This table should be used as a planning tool only (see tips for using the table on pp. 18–19). Producers must understand and use methods for estimating residue cover in the field to determine the actual potential of their field operations for controlling erosion.

Speed of Field Operations

As the size of farms becomes larger, the time available per acre to prepare seedbeds decreases. Understandably, producers are speeding up in order to complete planting operations in a timely fashion. Depending on the operation, a decrease of 2 mph may mean an increase of 10–20 percent in residue cover. Studies show that chisel plowing corn residue at 2–3 mph instead of 5–6 mph increases residue cover by 10 percent. Similarly, slowing to 3–4 mph from 6–7 mph when disking soybean stubble can increase residue cover by as much as 15 percent.

Depth of Field Operations

For various reasons, producers typically till the soil as deeply as their tractors can pull. Proper adjustments in tillage depth, however, can increase residue cover levels. For example, chisel plowing corn residue 5 inches deep can leave as much as 10 percent more residue cover than chiseling it 7 inches deep. For soybean stubble, disking 3 inches deep can leave 15 percent more cover than disking 5 inches deep. Several factors play a role in the effects of depth adjustments on residue cover, including soil moisture and soil type.

Angle of Field Operations to the Old Crop Rows

The angle of the field operation to old crop rows has significance for primary operations, such as chisel plowing and disking. At one time producers tilled at angles to the old crop row to improve the flow of residue through the machines. Modern equipment, however, is designed for high clearance and the flow of residue is not as important. Many field demonstrations show that tilling "with" or parallel to the old rows can leave significantly higher levels of residue cover than tilling at an angle to the rows.

Soil-Engaging Tools

The type of soil-engaging tool used can have a dramatic impact on residue cover. For example, the difference between sweeps and twisted points on chisel plows can mean as much as a 35 percent difference in nonfragile crop residues (table 4). A wide variety of soil-engaging tools are available.

Planters

Traditionally, two types of planter row units have been used—those with offset (staggered) double-disc openers and those with unstaggered or conventional double-disc openers. While similar in design, the two types can differ significantly in the amount of soil they move, especially when planting in fragile residues. Planter row units that have staggered double-disc openers leave more residue cover after planting. Other types of seed furrow openers include slot and runner openers. These are used primarily in wheat production areas and are slightly more aggressive in covering residues than disc openers.

Row-Cleaning Devices

Row cleaners are designed to move crop residue from the row in order to provide a cleaner seedbed for more accurate seed placement and more control of seed depth. Row cleaners typically include double-disc furrowers and horizontally mounted disks in ridge-till systems, and row-cleaning brushes and spoke or spider wheels in no-till and some conventional till systems. Limited research indicates that row cleaners can reduce surface residue cover by as much as 15 percent after planting into corn and soybean residue than if they were not used. Row cleaners are most effective when set to move only residue, but many producers set them so they also move a considerable amount of soil. The deeper that row cleaners are operated, the less the amount of residue cover remaining after planting.

Drills and Coulters

Two types of drills predominate in the North Central Region and small-grain-producing areas. These are (1) drills with offset or conventional double-disc openers (with or without a coulter caddy), which represent the majority used, and (2) drills with a single, angled disc opener. Hoe and furrow drills are also used to a lesser extent in western regions. Because drills with a single, angled disc opener have fewer parts that can move the residue and a smaller angle between the soil-contacting blade and the direction of travel, they leave more residue cover than drills with hoe, furrow, or double-disc openers.

Like planters, drills also offer the option of a coulter attachment. Unlike planters, though, only one coulter per row can be attached. The same types of coulters are used on planters and drills, so depending on the machinery combination, the amount of cover left after drilling can vary widely. The most aggressive combination, which leaves the least residue, is the 2-inch (or wider) wavy or fluted coulter with nonstaggered double-disc openers.

Fertilizer Attachments

Most planters and drills have fertilizer attachments. Used primarily for placing starter nitrogen fertilizer for no-till and conventional tillage corn, the attachments are usually in the form of knives or injectors that follow a narrow, rippled coulter. The residue cover that remains after planting can vary, depending on the settings (for example, the depth of knifing, the width of knife or coulter). As much as 15 percent more residue cover can be left after planting into fragile residue without starter fertilizer attachments than that left when planting with a knife attachment. If producers do not use starter fertilizer attachments, they need to employ some other method to apply the necessary fertilizer.

Using the Table as a Planning Tool

Operating depths, speeds, and equipment vary widely among producers. While it's possible to estimate the amount of residue cover, producers should always measure their residue to ensure that necessary levels are maintained. The two examples that follow show how to use table 4 for planning purposes.

Example 1

A producer who had a corn yield of 150 bu/acre the previous year used a chisel plow in the fall with 4-inch twisted points. The following spring he disked twice (tandem, 7- to 9-inch blade spacing) and field cultivated once (6-inch shovels). He planted the new crop, using a conventional planter with staggered double-disc openers. The winter months were mild, so there was maximum decomposition. Using table 4, the producer can select percentages for each operation. *Remember, there is no set rule for deciding which number to choose within the listed ranges. The highest number may represent optimal conditions (for example, above-average yield that results in high levels of residue cover) and the lowest number may represent poor conditions. A conservative approach would be to pick a number in the middle of the range.*

Field operation	**% Residue remaining (nonfragile)***
After harvest (high yield)	95
Chisel plow with 4-inch twisted points	60
Overwinter (mild winter)	80
Disk once	55
Disk once (the second time)	55
Field cultivate once	75
Plant, conventional	95

* Percentages obtained from table 4.

Multiplying the factors together gives the percentage of residue cover after planting, as follows:

$0.95 \times 0.60 \times 0.80 \times 0.55 \times 0.55 \times 0.75 \times 0.95 = 0.10$, 10 percent cover.

Since this system provides less than 30 percent cover after planting, it does not qualify as a conservation tillage system. If the producer uses spikes (or 2-inch straight points) instead of 4-inch twisted points, the results would equal

$0.95 \times 0.70 \times 0.80 \times 0.55 \times 0.55 \times 0.75 \times 0.95 = 0.11$, 11 percent cover.

In this example, switching points did not significantly increase residue cover after planting since three secondary operations were still used. However, switching points can make a difference in systems where secondary operations are limited to one or two passes with less aggressive tools, such as field cultivating once only. Omitting the two diskings (given that field cultivating once would provide a suitable seed bed) would leave about 32 percent cover after planting.

Example 2

A producer had 45 bu/acre of soybeans the previous year and wants no-till corn in the spring. He applied anhydrous ammonia with closing discs in the spring and used a no-till planter with 1-inch wavy (fluted) coulters. The winter was cold with little snowfall, so decomposition was minimal. Using table 4, the producer can estimate his remaining residue cover as follows:

Field operation	% Residue remaining (fragile)
After harvest (high yield)	85
Overwinter (cold winter)	80
Apply anhydrous ammonia	50
Plant, no-till	80

Calculating the same way as in example 1—

$0.85 \times 0.80 \times 0.50 \times 0.80 = 0.27$, 27 percent cover—

the percentage of residue cover after planting almost meets the definition of conservation tillage. Producers should remember that soybean residue is very fragile and that even some no-till systems will leave low levels of cover. Note that a major reduction in cover is likely to occur as a result of the action of the anhydrous applicator (and possibly the associated closing disks). As one of the cheapest forms of nitrogen, anhydrous ammonia is used as the primary form of nitrogen in most crop production systems. However, as this example shows, the anhydrous applicator unit can significantly reduce residue cover.

Some producers use anhydrous ammonia applicators without serious reductions in cover. They may use an applicator unit with knives on 60-inch spacing for 30-inch corn row spacing, with the result that the knives and covering disks run through only half the number of rows. Many producers use the ammonia applicators without attaching the closing disks.

Additional Sources of Information

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Table 4. Percentage of residue remaining following different tillage and planting operations

Implement	Nonfragile*	Fragile*
	% Remaining	
Plows		
Moldboard plow	0–10	0–5
Moldboard plow-uphill furrow (Pacific Northwest Region only)	30–40	NA
Disk plow	10–20	5–15
Machines That Fracture Soil		
Paratill/paraplow	80–90	75–85
V-ripper/subsoiler		
12–14 inches deep, 20-inch spacing	70–90	60–80
Combination tools		
Subsoiler plus chisel	50–70	40–50
Disk-subsoiler	30–50	10–20
Chisel Plows		
With sweeps	70–85	50–60
With straight chisel spike points	60–80	40–60
With twisted points or shovels	50–70	30–40
Combination Chisel Plows		
Coulter chisel plows		
With sweeps	60–80	40–50
With straight chisel spike points	50–70	30–40
With twisted points or shovels	40–60	20–30
Disk chisel plows		
With sweeps	60–70	30–50
With straight chisel spike points	50–60	30–40
With twisted points or shovels	30–50	20–30
Undercutters		
Stubble-mulch sweeps or blade plows		
With sweep/v-blade more than 30 inches wide	85–95	70–80
With sweeps 20–30 inches wide	80–90	65–75
Disk Harrows		
Offset		
Heavy plowing, more than 10-inch spacing	25–50	10–25
Primary cutting, more than 9-inch spacing	30–60	20–40
Finishing, 7- to 9-inch blade spacing	40–70	25–40
Tandem		
Heavy plowing, more than 10-inch spacing	25–50	10–25
Primary plowing, more than 9-inch spacing	30–60	20–40
Finishing, 7- to 9-inch spacing	40–70	25–40
Light tandem disk after harvest, before other tillage	70–80	40–50
One-way disk		
With 12- to 16-inch blades	40–50	20–40
With 18- to 30-inch blades	20–40	10–30
Single gang disk	50–70	40–60

—continued

Table 4.—Continued

Implement	Nonfragile*	Fragile*
	% Remaining	
Field Cultivators (Including Leveling Devices)		
Used as the primary tillage operation		
Sweeps, 12–20 inches	60–80	55–75
Sweeps or shovels, 6–12 inches	35–75	50–70
Duckfoot points	35–60	30–55
Used as a secondary operation following chisel or disk		
Sweeps, 12–20 inches	80–90	60–75
Sweeps or shovels, 6–12 inches	70–80	50–60
Duckfoot points	60–70	35–50
Finishing Tools		
Combination finishing tools		
With disks, shanks, and leveling attachments	50–70	30–50
With springteeth and rolling baskets	70–90	50–70
Harrows		
Springtooth (coil tine)	60–80	50–70
Spiketooth	70–90	60–80
Flextine tooth	75–90	70–85
Roller harrow (cultipacker)	60–80	50–70
Packer roller	90–95	90–95
Rotary Tillers		
Secondary operation 3 inches deep	40–60	20–40
Primary operation 6 inches deep	15–35	5–15
Rod Weeders		
Plain rotary rod	80–90	50–60
Rotary rod with semichisels or shovels	70–80	60–70
Row Cultivators, 30-Inches and Wider		
Single sweep per row	75–90	55–70
Multiple sweeps per row	75–85	55–65
Finger wheel cultivator	65–75	50–60
Rolling disk cultivator	45–55	40–50
Ridge-till cultivator	20–40	5–25
Unclassified Machines		
Anhydrous applicator	75–85	45–70
Anhydrous applicator with closing disks	60–75	30–50
Subsurface manure applicator	60–80	40–60
Rotary hoe	85–90	80–90
Bedders, listers, and hippers	15–30	5–20
Furrow diker	85–95	75–85
Mulch treader	70–85	60–75
Drills		
Hoe opener drills	50–80	40–60
Semideep furrow drill or press drill, 7- to 12-inch spacing	70–90	50–80
Deep furrow drill with more than 12-inch spacing	60–80	50–80
Single-disk opener drills	85–100	75–85
Double-disk opener drills (conventional)	80–100	60–80

—continued

Table 4.—Continued

Implement	Nonfragile*	Fragile*
	% Remaining	
Drills—Continued		
No-till drills and drills with attachments listed		
In standing stubble		
Smooth no-till coulters	85–95	70–85
Ripple or bubble coulters	80–85	65–85
Fluted coulters	75–80	60–80
In flat residues		
Smooth no-till coulters	65–85	50–70
Ripple or bubble coulters	60–75	45–65
Fluted coulters	55–70	40–60
Row Planters		
Conventional planters with		
Runner openers	85–95	80–90
Staggered double-disk openers	90–95	85–95
Nonstaggered double-disk openers	85–95	75–85
No-till planters with		
Smooth coulters	85–95	75–90
Ripple coulters	75–90	70–85
Fluted coulters	65–85	55–80
Strip-till planters with		
2 or 3 fluted coulters	60–80	50–75
Row-cleaning devices, which leave an 8- to 14-inch-wide bare strip using brushes, spikes, furrowing disks, or sweeps	60–80	50–60
Ridge-till planter	40–60	20–40
Overwinter Weathering†		
Following summer harvest	70–90	65–85
Following fall harvest	80–95	70–80

* See p. 16 for a list of fragile and nonfragile crops.

† In northern climates with long periods of snow cover and frozen conditions, weathering may reduce residue levels only slightly, while in warmer climates, weathering losses may reduce residue levels significantly.

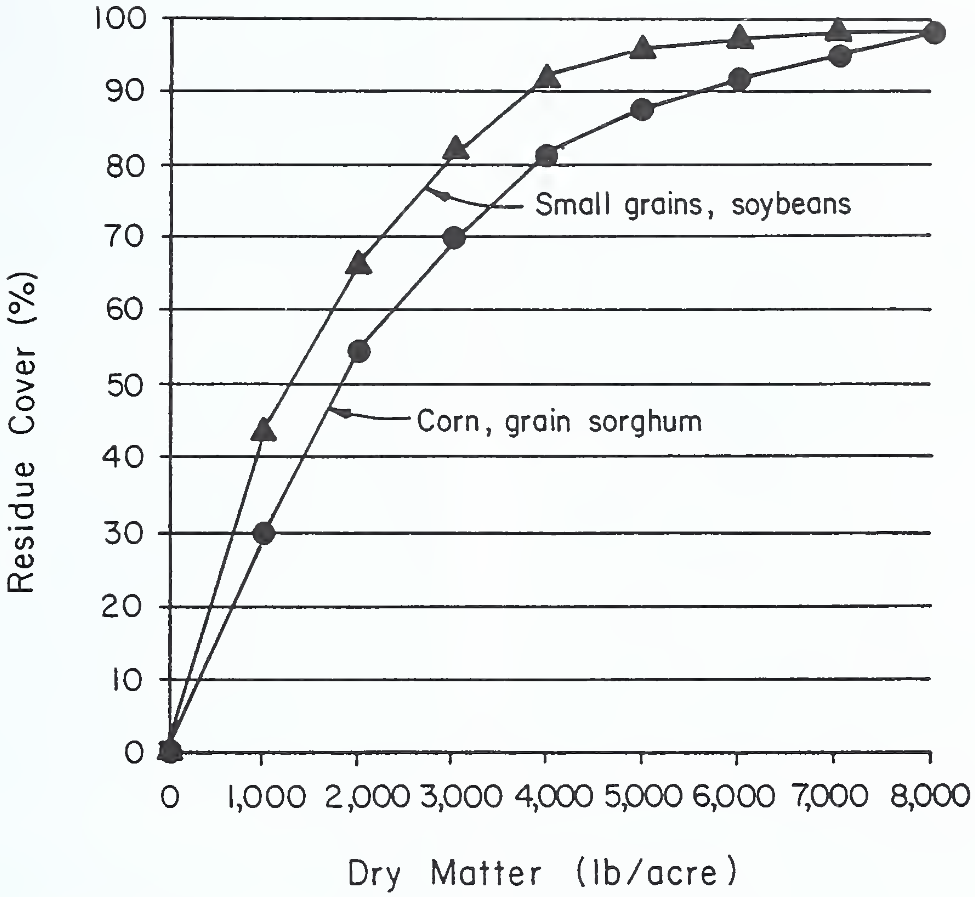

Figure 1. Relationship between production of dry matter and surface residue cover

7 The Profits of Crop Residue Management

Mike Monson and Nyle Wollenhaupt

Whether crop residue management is profitable depends on the system selected and the costs of production. In farming, as in most businesses, changes should be evaluated for profitability before they are adopted. If the switch to a crop residue management system requires new machinery, more expensive pest control, or higher cost fertilizers, it may take several years to achieve maximum efficiency.

The economics of crop residue management involves several issues. First, a producer can assess its profitability strictly as a crop practice by considering returns and costs. Second, higher crop residue cover reduces soil erosion, which provides secondary benefits that should be considered. Third, the advantages of residue management in meeting conservation compliance requirements should be weighed. One can categorize these advantages as follows:

1. Profitability. Crop residue management is often the least costly way to reduce soil loss to acceptable levels.
2. Flexibility. Any tillage practice and other management practices associated with increased residue are easily changed.
3. Portability. Crop residue management reduces soil loss while minimizing investment in structures—such as terraces and waterways—for any particular field or location.

An Historical Perspective

Farmers' attention to managing residue has historically turned on economic considerations. Early agricultural research focused on crop rotations or green manure crops as the principal method of maintaining soil fertility. In 1947, soil scientist M.F. Miller concluded, "The important thing, from the standpoint of continued crop production, is to provide, from rotation to rotation, or year to year, a regular and abundant supply of readily decomposable organic matter that is reasonably high in nitrogen. The decay of this within the soil will set free sufficient available nitrogen for satisfactory crop yields." However, industry refocused on fertilizer production the technology it had developed to produce nitrogen compounds as explosives in World War II, and the relatively low cost of synthetic nitrogen rapidly diminished the economic significance of residue management in providing plant nitrogen. This synthetic nitrogen permitted growing the most profitable crops in continuous sequence without interspersing green manure crops for nitrogen.

Economic considerations were again critical in the early 1970's with the rapid increase in fuel prices. As producers sought to minimize the cost and amount of tillage, the amount of surface crop residue increased. The chisel plow, which required less fuel and left significantly more crop residue on the surface, rapidly replaced the moldboard plow. The economic focus was on reducing the cost of tillage, not necessarily reducing soil erosion. Yet, producers found that they could maintain or even increase profits by leaving more residue on the surface, while simultaneously reducing soil erosion (Zinzer et al. 1985).

Income and Costs

The key in analyzing the economics of residue management in the North Central Region is its impact on the profitability of corn and soybeans. It is well documented that surface residue has positive effects on the physical properties of soil, such as bulk density, organic matter, moisture retention, permeability, and erodibility, but its effects on yield are less certain. Most studies find no statistical difference in crop yields when various amounts of residue are left on the surface during single-year trials. This conclusion seems obvious, since history teaches that producers would have adopted residue management practices if short-term studies showed a clear economic advantage.

Longer term studies of repeated trials show that crop yields improve with increased crop residue (see fig. 17, p. 91). Some portion of this yield benefit can be attributed to better soil fertility from increased organic matter and improved soil structure. However, one must also consider the long-term benefits of reduced soil loss on crop yields. For most soils in the North Central Region, productivity decreases as topsoil is lost. Economic analyses suggest these losses accrue so slowly that their value has rarely been the factor that motivated farmers to change their management system to prevent soil erosion (Monson 1982).

Operating costs

Crop residue management can affect the profitability of crop enterprises, even if one assumes it makes no impact on crop yields and gross returns. Leaving more residue on the surface involves less tillage, less fuel, and fewer hours of labor per unit of production than conventional tillage systems. And, good crop emergence can be achieved by preparing only a very narrow strip, which can translate into savings in seedbed preparation.

Many herbicides used in conventional systems also work in residue management systems, perhaps at heavier rates and with an adjuvant to assist penetration and adherence to crop residues. While weed control problems in crop residue management systems will arise as the nature of the weed population changes, such problems will probably be no worse with higher levels of residue, only different. Conventional tillage prepares a seedbed not only for the crop but for weed seeds as well. Refraining from tillage leaves seeds on the surface to rot or to be eaten by birds rather than burying them where they will germinate. Residue left on the surface also serves as a mulch that reduces the need for cultivation and conserves moisture.

In no-till systems burndown herbicides substitute for tillage, and the increased cost of weed control can reduce the savings realized from less fuel and labor. Experienced no-tillers use early preplant and split application herbicide programs to keep costs—and weeds—in check. By spot spraying problem areas rather than the whole field, one reduces costs and the amount of herbicides used regardless of tillage system.

Fertilizer management also presents some problems with high crop residue systems. High levels of crop residue on the surface can limit the effectiveness of surface-applied liquid nitrogen that contains urea. Use of a knife applicator to inject liquid or gaseous nitrogen fertilizer into the soil reduces surface residue by an average of 12 percent (Burr et al. 1986). While continuous corn may provide enough residue to tolerate such a degree of residue burial, other crops may not. Producers need to recognize the potential for residue reduction when developing their total tillage system.

Research indicates that either anhydrous ammonia or urea-nitrogen solution (50 percent urea-nitrogen) injected into the soil provides consistent performance (Bucholz 1992). Broadcast or surface-applied ammonium nitrate is equally effective in providing nitrogen. In most cases, the higher cost per pound of nitrogen in ammonium nitrate offsets the cost of owning an applicator or performing a custom application of anhydrous ammonia or urea-nitrogen.

Potassium and phosphorus are not lost by volatilization and consequently do not require immediate incorporation by tillage into the soil. Rain washes them in and makes them available to growing crops. Although tillage more evenly distributes these nutrients in the upper 6 inches of soil, it provides no additional benefits in terms of crop yields. By reducing evaporation, surface residue maintains a higher water content near the surface, which favors the growth of more feeder roots near the surface where nutrients concentrate. As mentioned, crop residue management also reduces losses of crop nutrients from erosion.

With newer planting and nitrogen-injection equipment, seed and fertilizer costs in crop residue systems should not differ substantially from conventional tillage systems. The hours of required labor decrease by as much as 60 percent per acre, and fuel costs can be reduced by the same amount. Chemical costs should increase no more than $5–$15 per acre.

Ownership costs

Ownership costs include interest, taxes, depreciation, and insurance on buildings and equipment. Most newer planters and drills come equipped to plant in residue. Attachments, such as special coulters and down-pressure springs, add limited extra costs. Government programs can reduce the cost of these investments.

Increased surface residue means decreased tillage, and tillage equipment lasts longer when used less. The average fixed cost per acre of any tillage equipment does not decrease by increasing the number of passes on a given acre; rather, its cost decreases only by increasing the total acres covered. So, the per-acre fixed costs of a disk are no different if each acre is disked once or twice. However, if the disk lasts twice as long because it is used only once per acre, fixed costs per acre will be cut in half. Additional cost savings can be realized if unused equipment is sold.

The horsepower requirements of a tractor are often less when residue is left on the surface. No-tillage even allows many producers to eliminate primary tillage tractors. Chisel plows and one-pass tillage systems, however, still require access to higher horsepower tractors. With machinery operated at maximum efficiency—assuming a complete switch to no-till—annual machinery costs can be reduced 40–50 percent, which translates into $15–$20/acre savings for most farmers in the North Central Region.

Conservation Compliance and Residue Management

The most direct effect of residue management on farm profitability is its ability to help meet conservation compliance provisions. The value of government price supports under the 1985 Food Security Act is the most compelling reason for adopting soil conservation practices. In recent history, these payments have provided as much as 50 percent of net farm income—the difference between a profit and a loss for many farmers.

Profitability

How does crop residue management help provide a least-cost solution to conservation compliance? Many farmers originally chose terrace systems as the primary means to achieve conservation compliance because these required the least change in farming practices and crop rotations. Crop residue management was selected only when terraces alone were not sufficient to reach compliance goals. Farmers are faced with the high initial investment in terraces, even with cost-share programs. On some soils, the farmer's share of the cost of terraces can exceed $100 per acre (Wollenhaupt et al. 1988)—a cost that can present cash flow difficulties. Amortizing this investment over 20 years still amounts to an annual cost of $10 per acre. And, unlike an investment in new machinery, an investment in terraces cannot be spread out over more acres.

Crop residue management increases the effective life of terrace systems by reducing soil erosion between terraces. Adopting residue management practices permits wider spacing of terraces, thus reducing the per-acre cost. On steep soils, crop residue management may need to be combined with terraces to adequately control erosion and provide a profitable and sustainable cropping system.

The cost of terraces, even just the producer's share, is rarely captured in higher land values (Miranowski 1984). Some potential buyers who are averse to keeping residues on the surface may be willing to pay a higher price based on the amount the seller has invested in terraces. However, buyers who rely on surface residue management to meet compliance provisions may even discount terraces as an inconvenience because the terraces force them into field traffic patterns that increase costs.

Flexibility

New technologies for crop residue management have developed rapidly in response to the conservation compliance provisions of the 1985 Food Security Act. Machinery manufacturers recognize the market for tillage equipment that maintains crop residue. New herbicides are advertised to work well in high residue systems. As experience with crop residue management increases, adoption of new technologies will become easier and more profitable, and crop residue management technologies will be applied across the farm, spreading the cost of equipment over more acres.

Because it reduces tillage, crop residue management makes it easier to preserve contour lines when contouring is part of the conservation system. The reduction in soil erosion may even eliminate the need for contouring, thereby avoiding point rows. A farmer using mulch tillage or no-tillage can change the direction of tillage or planting from year to year. If wind erosion is a concern, the farmer can plant strips at right angles to the dominant wind direction and still keep soil erosion at an acceptable level. As new, more cost-effective practices and equipment are developed that operate best with different row spacing or equipment of different widths, they are easily incorporated in crop residue management systems.

As mentioned, crop residue management practices are beneficial in terrace systems. To minimize the initial cost, farmers often space their terraces to provide just enough erosion control, given the current crop rotation and tillage practices. Unfortunately, when prices or costs change to favor a more erosive crop, a farmer cannot very well narrow this terrace spacing. Some producers incur the costs of substituting conventional tillage for established terrace systems that are not adequate for conservation compliance. Use of crop residue management on terraced fields provides a profitable alternative.

Portability

Farmers who practice crop residue management have a competitive edge in renting land. For example, most tenant farmers are reluctant to invest in terraces on someone else's land. However, rented acres can often be brought into conservation compliance through residue management practices without requiring the landlord to invest in conservation structures. This, combined with continued eligibility for government programs and the ability to produce crops with the highest returns, can be very appealing to a tenant. Residue management reduces the labor, fuel, and machinery requirements that a tenant typically provides, and this reduction increases the profitability of renting land. As land enrolled in the Conservation Reserve Program is released, producers who use crop residue management will have the same competitive advantage whether they purchase or rent this land.

Costs of Soil Erosion

Soil erosion reduces productivity through loss of organic matter, reduced water-holding capacity, shallower root zone, and loss of plant nutrients (see chapters 1, 17, and 18 for fuller discussions.) Costs are also incurred when replanting is necessary because of damage to seedlings from wind erosion or because of crusting from too little residue on the surface or too little residual organic matter in the soil. Sediment buries fences and fills open drains, waterways, and streams. Small gullies can damage machinery and increase repair costs, and larger gullies destroy the value of land for crop production and can reduce the value of adjacent land. The farmer eventually bears these costs yet may not directly attribute them to soil erosion. Water quality is affected by nutrients and pesticides attached to soil particles. As a member of society, the farmer also shares these costs.

In the past, lost productivity as a result of soil erosion had very little economic impact. For example, a commercial fertilizer could cheaply replace any plant nutrients lost with the soil. Assuming a very conservative 2 percent loss in yield from erosion, 100 bushels of corn at $2.50 a bushel discounted at 5 percent interest, would produce an annual cost from erosion of just over $2/acre/yr. While $2 an acre seems insignificant, restrictions on the application of fertilizer could potentially increase this cost dramatically. The economics of maximizing profits dictate that the last unit of fertilizer applied generates just enough additional yield to cover its cost. As fertilizer use is restricted, inherent soil fertility will have greater economic value. The returns to a soil that has more inherent fertility will be greater than those to soils that have lost productivity to erosion.

Over time, improved varieties and techniques have increased yields and hidden long-term losses in soil productivity from erosion. Extended trials produce considerable differences in yield under different residue management systems. In an 8-year study, McGregor et al. (1992) showed that continuous soybeans managed with conventional tillage averaged a 5 percent greater yield during the first 3 years than those managed with no-till, but that the no-till soybeans yielded 44 percent more than the conventionally tilled soybeans during the last 5 years. Most of this difference resulted from decreasing yields under conventional tillage, while no-till yields remained relatively constant. Few farmers would deplete the organic matter of their soils to the level reached with conventional tillage in this trial, but the comparison illustrates the value of residue management in maintaining soil productivity and, ultimately, profitability.

Farmers who use crop residue management find they can handle more acres or devote more time to livestock enterprises or even a second job. These opportunities translate into larger profits. Crop residue management, like any farming practice, requires a positive attitude for success. A farmer can let it fail. However, there are cost-effective solutions to its problems, which can be adapted to a producer's resources to achieve a more profitable and sustainable farming system.

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8 Fertilizer Management

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Success with conservation tillage systems depends in part on fertilizer management. Tillage influences the physical properties of soil, and these can change the soil nutrient status and the ability of crops to access nutrients. When tillage is reduced to leave crop residues on the soil surface, the soil may be cooler, wetter, less aerated, and denser. This chapter examines the ways in which tillage influences nutrient availability and suggests management strategies that minimize fertility as a yield-limiting factor in conservation tillage systems.

Nitrogen

Nitrogen can assume many different forms in a soil system. To understand how tillage affects nitrogen availability one first needs to understand the nitrogen cycle. Most changes in the form nitrogen takes are due to soil microbial activity, which is sensitive to soil temperature, moisture, and aeration. Tillage affects all of these physical properties.

Only the nitrate and ammonium forms of nitrogen are available to crops. Nitrate is a negatively charged ion (NO_3^-) that is very mobile in soil and moves with soil water. The nitrate form of nitrogen can be lost from leaching as nitrate or in bacterial conversion to gaseous forms that are unavailable to plants, primarily diatomic nitrogen gas N_2. About 79 percent of the atmosphere comprises this gaseous form of nitrogen, which is not available to non-nitrogen-fixing plants such as corn and small grains. Plants get most of their nitrate from the transpirational stream of water they take from the soil.

Ammonium is a positively charged ion (NH_4^+) that is held by negatively charged soil clay. Ammonium is taken up actively and moves to plant roots by diffusion. It acts like potassium does in soil, so a good way to recover appreciable amounts soon after application is to place it close to the row, like one does with potassium. However, unless a nitrification inhibitor is applied with the ammonium fertilizer or the fertilizer is applied after soil temperatures fall to less than 50 °F, the ammonium usually converts to nitrate in a biochemical oxidation process called *nitrification*. With warm soil temperatures (greater than 70 °F) this conversion to nitrate occurs within a few weeks.

Effects of Tillage on Organic Nitrogen Sources

Crops get part of their nitrogen from the mineralization of organic sources of nitrogen, such as soil organic matter, animal manures, and plant residues from previous years. Mineralization of nitrogen involves the microbial conversion of organic forms of nitrogen—proteins and amino acids—to ammonium. Crops also utilize nitrogen stored in the soil as nitrate or ammonium. The rest of the nitrogen needed must be applied as fertilizer.

Tillage can alter the amount of nitrogen mineralized from soil organic matter because it affects aeration and soil temperature. Full-width, deep tillage, such as chisel plowing or deep disking, results in a soil density similar to that left after moldboard plowing. With systems that eliminate primary tillage, such as shallow disking, ridge tillage, or no-tillage, less nitrogen mineralizes from soil organic matter. Systems using less tillage tend to increase soil organic matter. The following tabulation shows the effect of 8 years of tillage on soil organic matter in the top foot of a Seaton silt loam soil (Typic Hapludalf) in southeastern Minnesota (Moncrief and Olness 1988):

	Organic carbon (%)	**Organic matter** (%)
No-till*	1.30a†	2.24a
Chisel plow‡	1.16b	2.00b

* The no-till system used a planter equipped with a 2-inch fluted coulter and was not cultivated.

† Means within the same column followed by the same letter are not statistically different at $\alpha = .01$.

‡ The chisel plowing was done in the spring with a coulter chisel equipped with 4-inch-wide twisted shovels; it was followed by one finishing pass with a field cultivator.

Under no-till conditions appreciable amounts of nitrogen (about 40–100 lb/acre/yr) are incorporated into accumulated organic matter. In the early years of no-till management—while the buildup of organic matter is occurring—more nitrogen is often required to achieve yields equal to those of more intensively tilled soil, where more rapid oxidation of organic matter mineralizes organic nitrogen and makes it available to the crop (see chapter 17 for more details on the role of organic matter in fertility).

Tables 5 and 6 show other effects of tillage on soil nitrogen in a study on a Fargo silty clay soil with poor internal drainage and 4.1 percent organic matter. It was found that tillage increased the amount of nitrogen present in the soil as nitrate in the spring. This study showed that nitrogen needs to be applied based on the results of a soil test and to meet specific tillage requirements. Although tillage did not affect average barley protein concentrations and yields, there was an interaction between the type of tillage and the level of nitrogen. When adequate nitrogen was applied, the protein concentrations and yields were higher with the chisel and no-till systems than with the moldboard plow.

In west central Minnesota, a 6-year study evaluated the response of continuous corn to different tillage systems and a fall-applied anhydrous ammonia nitrogen source; the soil was a silt loam soil with somewhat poor internal drainage and 5.4 percent organic matter (fig. 2). The study showed that reduced tillage—because it does not result in the same amount of organic matter being mineralized as moldboard plowing does—requires some additional fertilizer nitrogen for equivalent yields (see chapter 17 for a more detailed discussion). In the early years of tillage systems that eliminate full-width, deep primary tillage, it is common for corn yields to increase in response to nitrogen fertilization. At the higher rates of applied nitrogen, the grain yields were similar regardless of tillage system; these results were similar to those obtained in the barley study (table 6).

Nitrogen From Fertilizer

One of the major concerns when managing nitrogen in commercial fertilizers is prevention of volatilization losses from urea nitrogen sources, including urea-ammonium nitrate solutions and dry urea. Volatilization is the loss of nitrogen as ammonia gas, a process that occurs during the hydrolysis of urea. When urea combines with water (hydrolysis) in the presence of the enzyme urease (which is ubiquitous in natural systems), ammonium carbamate forms, which degrades to ammonia and carbon dioxide gases, which can be lost to the atmosphere (equation following).

$$CO(NH_2) + H_2O \rightarrow H_2NCOONH_4 \rightarrow 2NH_3 \uparrow + CO_2^{=} \uparrow$$

However, when this reaction takes place in soil solution, most of the ammonia is converted to ammonium (NH_4^+) and absorbed onto the soil particles. The conversion of ammonia to ammonium is more complete in acid soils than in basic soils. The risk of volatilization losses (and potential immobilization[1] loss) with urea fertilizer is illustrated by a study conducted in central Minnesota on an irrigated loamy sand soil (fig. 3). Different residue levels were established by using moldboard plow, chisel plow, ridge till, or no-till systems. A 28-percent urea-ammonium nitrate solution was broadcast on the surface, dribbled in a surface band, or injected behind a knife. As the level of corn residue increased, the corn grain yield decreased. Some of the applied ammonia left on the residues probably volatilized. Part of it may have been incorporated into the residues and their decomposition products by microorganisms, eventually becoming part of the higher organic matter found in long-term no-till soils (see chapter 17). When the solution was injected, crop residue had a much smaller influence on grain yields. Dribbling the solution on the soil surface decreased the surface area of contact and improved grain yields, compared to broadcasting the fertilizer.

If an ammonium nitrate solution is used as a nitrogen source, it should be incorporated or injected below crop residues if a full return on the investment is needed during the first year. Ridge-till systems provide opportunities for incorporation at planting and cultivation.

In conservation tillage systems, the most consistently performing nitrogen is anhydrous ammonia that is knifed in. This application (1) causes the nitrogen to remain in the soil longer as ammonium, a positively charged ion that the soil holds, (2) reduces denitrification losses because ammonium cannot be denitrified, and (3) places the nitrogen below the crop residues, so they cannot immobilize as much of it. Denitrification is the bacterial reduction of nitrate nitrogen to gaseous forms, which are unavailable to plants. Denitrifying bacteria are active under anaerobic conditions.

Nitrogen From Alfalfa

The tillage method used on corn following alfalfa has also been shown to have a significant effect on nitrogen response. In a study in north central Minnesota, the spring tillage treatments selected were moldboard plowing, disking with a light finishing disk, or no-tillage. The soil was a Verndale sandy loam (Udic Argiboroll), and the texture ranged from a loamy sand in the top 20 inches to a coarse sand below. Organic matter was 2.8 percent in the surface 10 inches; there was little organic matter below this depth. Nitrogen was applied as urea at the eight-leaf stage of growth and was followed immediately by irrigation with .25 inch of water to minimize volatilization losses.

The first-year corn grain response following 3-year-old stands of alfalfa in 1987 and 1990 are shown in figs. 4 and 5, respectively. The response to applied nitrogen was greatest with no-till. Disking resulted in an intermediate response. There was very little response to applied nitrogen after moldboard plowing because the plowing accelerated biological oxidation of the alfalfa residues, mineralizing the nitrogen and making it quickly available to the corn crop. In 1987 early summer temperatures were warmer and more favorable for mineralization than they were in 1990. This trend was also supported by grain protein data, which the figures do not show. The effect of tillage on nitrogen response may differ depending on climatic variability.

The alfalfa in this study was killed with herbicides in the spring. Studies in Idaho showed that fall or late summer killing of alfalfa with herbicides allowed sufficient mineralization of nitrogen from the alfalfa residues to meet the needs of corn the following year but did not allow sufficient mineralization to supply the needs of winter wheat planted a few weeks after the alfalfa was killed (David Carter, personal communication, March 1994). Other data from Minnesota suggest that fall killing is preferable on medium- to fine-textured soils.

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[1] Immobilization is the conversion of mineral forms of nitrogen—nitrate and ammonium—to organic forms, such as protein and amino acids, either by microbes or plants.

The study findings show that a producer who plans to plant corn into alfalfa with little or no tillage should also consider a nitrogen rate based on the time the crop will need nitrogen, the time the alfalfa is killed, and the degree of tillage to be used. The nitrogen made available from alfalfa residues cannot be estimated with a test since it is released during the season as decomposition progresses.

Nitrogen From Manure

In animal manures, the nitrogen associated with the urine is primarily urea and uric acid. These two substances are rapidly converted to ammonia after excretion. Unless special conserving structures are built in feed lots and loafing pens, most of the nitrogen from urine is lost. Steenvoorden published a good review of manure management in 1989.

Nitrogen associated with fecal material consists of organic compounds that decompose at varying rates. The mineral nitrogen portion of manure is similar to commercial fertilizer, such as urea, and commonly becomes adsorbed ammonium. The nitrogen associated with the organic portion (fecal material) is similar to other organic nitrogen sources, such as alfalfa and soil organic matter.

The two most likely effects of tillage on crop-available nitrogen from manure are (1) reduction of the risk of the ammonia being volatilized, because it is incorporated into the soil and (2) more rapid mineralization of the organic portion, resulting from more moisture and optimum temperature for microbial degradation in the soil. Injection of manure eliminates most volatilization losses of ammonia.

When injecting manure, sweep or horizontal disk-type openers have several advantages over chisel points. They leave more crop residue on the surface for erosion control. Volatilization losses are less likely. Erosive losses of phosphorus from manure and the potential eutrophication of surface water is greatly reduced.

In a study in southeastern Minnesota the effects of tillage associated with manure injection and chisel plowing illustrated utilization of manure in residue management systems. Manure was applied every year in one treatment and fertilizer nitrogen was applied every year in a separate treatment. In a third treatment, manure was applied every other year. It was injected about 6–8 inches deep with a 3,250-gallon applicator equipped with 6-inch sweeps. The two tillage systems evaluated were (1) no-tillage, other than that associated with spring manure injection in years with application, and (2) chisel plowing in the spring followed by a field cultivator. In years when manure was applied, no-tillage was a misnomer, but corn was planted with no other tillage.

One goal of the study was to incorporate broadcast manure or to mix injected manure while leaving adequate residue cover to protect against erosion. The effects on soil cover of the equipment used in manure injection are shown in figure 6; soil cover was measured in the row and between the rows. Corn growth and development was negatively correlated with in-row cover; erosion control was positively correlated with between-row cover. The first pair of bars in figure 6 shows the effect on in-row and between-row residue cover of a 2-inch fluted coulter mounted on a no-till planter. The in-row cover is higher than the optimum level for growing corn. The second set of bars shows the effect on surface residue of a manure injector equipped with sweeps and a 2-inch fluted coulter on the no-till planter. There is still adequate soil cover between the rows for erosion control. The third set of bars shows the residue left after chisel plowing with 4-inch twisted shovels followed by the action of the coulters mounted on the planters. The last pair shows the cover after manure injection with subsequent chisel plowing and action of the coulters. The study illustrates that use of sweeps on manure injection equipment helps maintain adequate between-row soil cover for erosion control, while bringing in-row cover down to levels that result in better yields.

Table 7 shows corn grain yields after fertilizer and manure applications in a study of no-till and chisel plow systems. The nutrient content of the manure in the study was quite consistent from year to year. The effect of tillage on the mineralization of soil organic matter and the release of nitrogen is reflected in yields from the check plots, where no nitrogen was added (66 and 87 bu/acre for the no-till and chisel systems, respectively. These yields indicate that substantially more nitrogen was left unmineralized in organic matter in the no-till plots. In other words without tillage the nitrogen remains tied up in the organic matter. The yields in the year after manure application illustrate the influence of tillage on soil organic matter and organic nitrogen from manure. The higher yield of 130 bu/acre for the chisel system reflects the higher mineralization rate and the higher release of organic matter from the soil and the added manure. Higher levels of organic matter retain more nitrogen that is not immediately available to corn when tillage is reduced; this fact is illustrated by the lower 121 bu/acre yield with no-till.

Phosphorus and Potassium

Availability

Physical soil properties such as temperature, moisture, and aeration and the spacial distribution of phosphorus and potassium can affect the availability of these nutrients to the crop. Plant properties such as root distribution, root metabolism (effects on active uptake), and nutrient requirements can also affect the availability of phosphorus and potassium.

Tillage influences many of these interacting soil and plant properties. For example, the higher soil moisture found in crop residue management systems can be beneficial to crops. A review of research examining the effects of soil changes in the Midwest can be found in Moncrief et al. 1986.

Many researchers have documented the vertical stratification of immobile nutrients, such as phosphorus and potassium, that occurs with conservation tillage. In areas where rainfall is adequate most researchers report no difference in the availability of phosphorus as a result of tillage. The most common explanation for the availability of stratified phosphorus in the upper soil is an increase in root activity in this region, which comes from the higher moisture content that accompanies residues. If the surface soil dries out and the roots become inactive, it seems possible that the nutrients in the soil would not be available to the crop. This unavailability may pose a problem in drier areas of the Midwest on soils with low subsoil phosphorous.

The literature is divided on the effects of tillage on potassium availability. Some researchers find that conservation tillage systems result in potassium being more available, some find it less available, and some find no difference in availability. In the North Central Region most researchers have found a reduction in potassium availability with systems that eliminate full-width, deep tillage, such as shallow spring tillage with a disk or field cultivator, ridge till, or no-till. Soils that have shown a tillage-induced reduction in potassium availability ranged in parent material from glacial outwash to glacial till and loess. Researchers have consistently found that modest amounts of row-applied starter fertilizer (10–20 lb K_2O/acre applied with the planter or banded near the row) effectively overcome any availability problems (fig. 7).

Interpreting Soil Tests

When applied phosphorus and potassium are not mixed uniformly in the top 6–8 inches of soil, spacial considerations are necessary when interpreting soil tests. Generally speaking, broadcast phosphorus and potassium, when not tilled deeply into the soil (as in chisel plowing or disk systems), show higher levels in soil tests than when they are more deeply tilled, as with moldboard plowing. Soil nutrients are more concentrated near the surface, and soil tests reflect this. If the upper region of the soil is moist enough of the time—so feeder roots grow into this region—conservation tillage benefits the crop's recovery of soil phosphorus and potassium. Many soils tend to fix either phosphorus or potassium and sometimes both in compounds relatively unavailable to plant roots. For this reason a banded application near the row is often the most efficient on these soils.

A ridge-till system poses a unique problem when interpreting soil tests. During cultivation to build ridges, soil phosphorus (P) and potassium (K) are moved into the rows or ridges, and thus, their measured P and K levels are higher than average if samples are taken from the ridges. During planting, the ridge is scalped and thrown between the rows. Probably the best time to sample, then, is after planting but before ridging. If soil samples cannot be taken at this time, then they should be taken halfway up the ridge.

Liming

Low soil pH can limit nutrient availability, rhizobium activity of legumes, and effectiveness of triazine herbicides (atrazine, simazine, and metribuzin). Broadcast applications of ammoniacal sources of nitrogen (urea, ammonium nitrate, and ammonium sulfate) in tillage systems that provide little incorporation will reduce the surface pH (Moschler et al. 1973). Research shows that corn responds to surface lime applications under long-term no-till conditions in a humid climate similar to that found in the eastern states of the North Central Region (see chapter 17 for further details). In the western states of the North Central Region, liming is not as important because most of the soils are calcareous.

Of the common crops, alfalfa is the most sensitive to soil pH. To grow it soil pH should be maintained close to neutrality (7.0). Lime should be applied immediately ahead of alfalfa in the crop sequence because pH of the soil surface commonly declines faster under no-till management.

Before adopting a reduced tillage system, the producer should use soil tests to determine the amount of lime needed and then incorporate the lime 6–8 inches deep. Thereafter periodic surface liming can keep pace with surface acidity from surface-applied nitrogen. The amount of lime needed should be based on the amount of nitrogen applied (4 lb lime/1 lb nitrogen) or on 0- to 3-inch soil samples (indicate the sampling depth when sending samples to the laboratory).

General Pointers

Michigan, Minnesota, South Dakota, Wisconsin

In a conservation tillage system (no-till, ridge till, light spring disking) used after alfalfa or clover, decrease the estimate of legume nitrogen available to the succeeding crop by about 20 percent, because less of the residue mineralizes and more remains as soil organic matter.

In a conservation tillage system, when evaluating the amount of nitrogen available from organic manure sources in years after application, decrease the credit by 20 percent because this portion of the nitrogen goes into increasing soil organic matter.

If corn or small grains follow corn or small grains and a spring soil nitrate test cannot be done, increase the nitrogen rate over that recommended by 30 percent for no-till and 15 percent for ridge till, compared to plowed systems.

If corn or small grains follow a low-residue crop such as soybeans or sunflowers, use the recommendations developed for moldboard plowing systems regardless of the tillage system used.

If a full-width, deep tillage system is used, such as chisel plowing or deep disking, use the nitrogen recommendations for moldboard plowing systems regardless of the crop sequence. In the northern part of the region, nitrogen in starter fertilizers is not usually cost-effective unless the soil is sandy.

Illinois, Indiana, Missouri, Ohio

Use starter fertilizer with equal amounts of nitrogen, phosphorus, and potassium (such as 10–10–10).

Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota

Incorporate urea nitrogen within 2–3 days after application. Banding of phosphorus and potassium near the row is recommended.

In drier areas (20 inches/yr or less), place the starter fertilizer deeper than the usual 2–4 inches. Keep phosphorus and potassium bands within 4 inches of the corn row. Continue to take soil samples 0–6 inches deep for phosphorus and potassium analysis.

With a ridge-till system, take soil samples after planting but before cultivation. During other times of the year, only take samples halfway up the ridge.

Take a sample 0–3 inches deep to determine pH, if there has been a history of surface-applied nitrogen and triazine herbicides are to be used.

When alfalfa is rotated with corn, apply lime in the corn years to allow more reaction time. If rainfall is at least 30 inches/yr, incorporation and complete soil mixing is not necessary for adequate soil reaction.

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Table 5. The effect of tillage and the previous crop on nitrate levels and barley yields following soybeans on a Fargo silty clay (Vertic Haplaquoll) in northwestern Minnesota

	Tillage		
Variable	**No-till**	**Chisel plow**	**Moldboard plow**
Previous crop	---------------------lb nitrate-nitrogen/acre*--------------------		
Soybeans	53	55	75
Barley	43	71	99
Average	43	63	87
Nitrogen rate			
(lb/acre)	---------------------------bu/acre yield---------------------------		
0	51	53	56
30 or 55†	62	60	57
Average	57	57	56

* The nitrate levels were determined from soil testing to a depth of 2 feet in the spring 1988.

† Nitrogen was applied in the spring as broadcast urea at a rate based on the spring soil nitrate test. The barley grown in the no-till and chisel systems received 55 lb/acre, and the barley grown in the moldboard system received 30 lb/acre.

Source: Moncrief et al. 1989.

Table 6. The effect of tillage on barley protein concentrations and yields following soybeans on a Fargo silty clay (Vertic Haplaquoll) in northwestern Minnesota

Nitrogen rate (lb/acre)	**No-till**	**Chisel plow**	**Moldboard plow**	**Average**
	------------------------------------percent protein-------------------------------------			
0	12.0	12.3	13.0	12.4
30 or 55*	13.5	13.7	13.2	13.5
Average	12.7	13.0	13.1	
	------------------------------------lb protein/acre-------------------------------------			
0	256	271	305	276
30 or 55*	347	342	312	333
Average	301	306	307	NA

* Nitrogen was applied in the spring as broadcast urea at a rate based on the spring soil nitrate test. The barley grown in the no-till and chisel systems received 55 lb/acre, and the barley grown in the moldboard system received 30 lb/acre.

Source: Moncrief et al. 1988.

Table 7. The effect of tillage method and fertilizer applications on corn grain yields

	No-tillage		Chisel plow	
Fertilizer application	bu/acre	Percent of maximum yield	bu/acre	Percent of maximum yield
Annual fertilizer*	149	97	153	100
Annual manure†	153	100	153	100
Biennial manure†				
Year of application	146	95	147	96
Year after application	121	79	130	85
None	66	43	87	57

* Fertilizer included 180 lb of anhydrous ammonia nitrogen/acre, which is the amount of nitrogen estimated to be available in the manure. This estimated level was calculated as 30 percent of the organic nitrogen plus all of the ammonium nitrogen.

† This manure was a liquid dairy manure obtained from an anaerobic pit below a barn. When applied at the rate of 9,500 gal/acre, it had a nutrient content of 143 lb/acre of ammonium nitrogen (from urine) and 115 lb/acre of organic nitrogen (from feces), for a total nitrogen content of 258 lb/acre.

Source: Joshi et al. 1991.

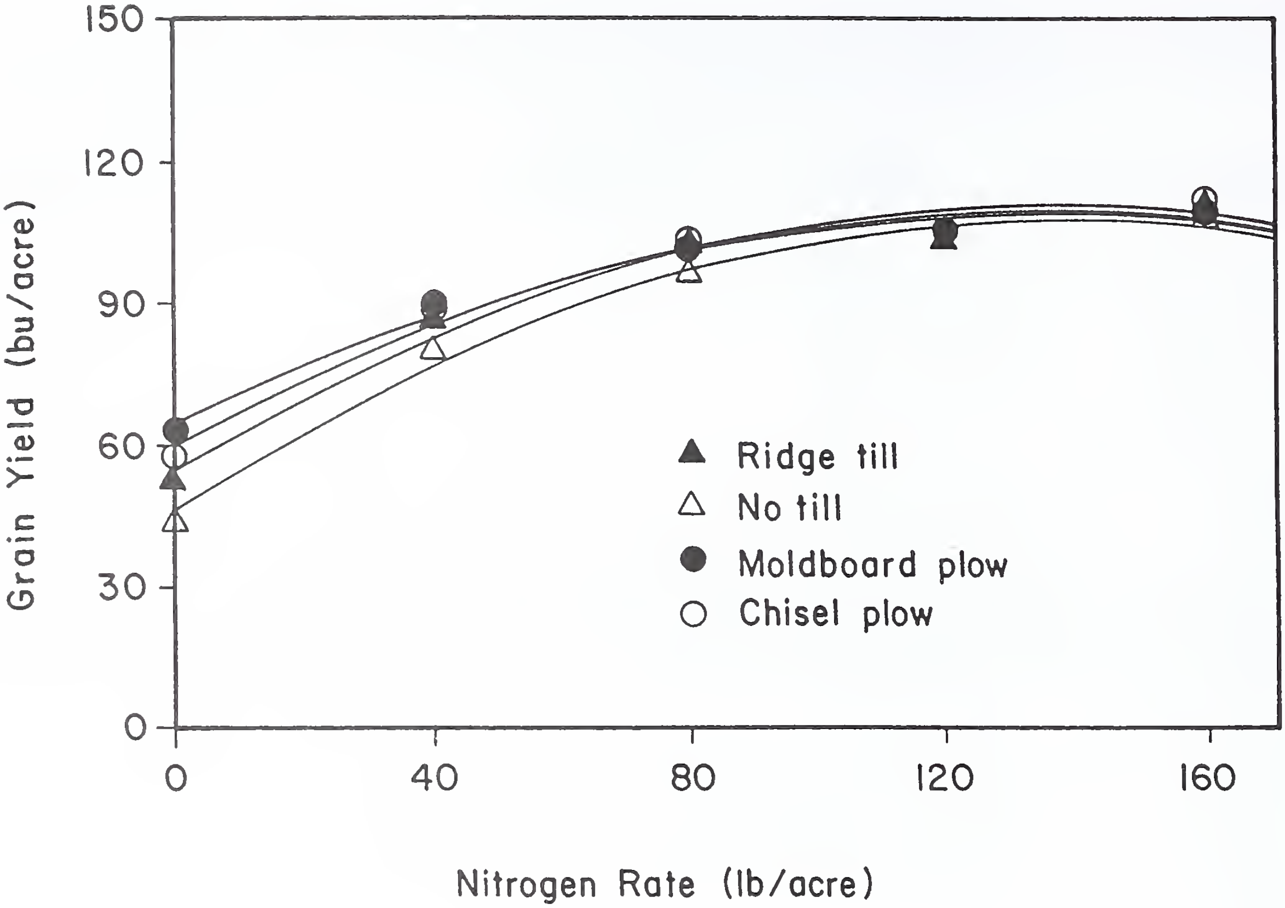

Figure 2. Effect of tillage on nitrogen response by continuous corn in a Pachic Udic Haploboroll-Tara silt loam and 5.4 percent organic matter, Morris, MN, 1984–89. Source: Moncrief et al. 1990.

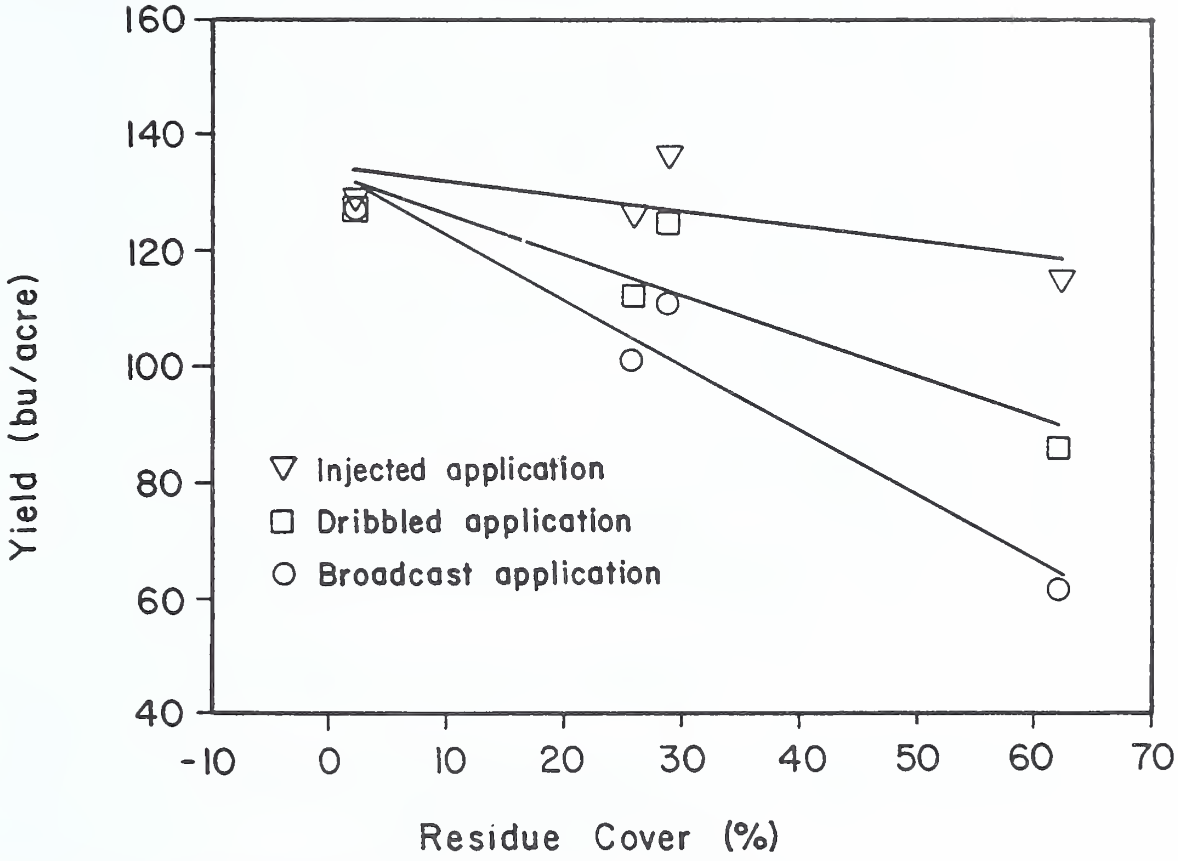

Figure 3. Effect of crop residue and method of applying urea-ammonium nitrate solution on corn grain yields in a Hubbard, loamy sand Udorthentic Haploboroll. Source: Malzer et al. 1985.

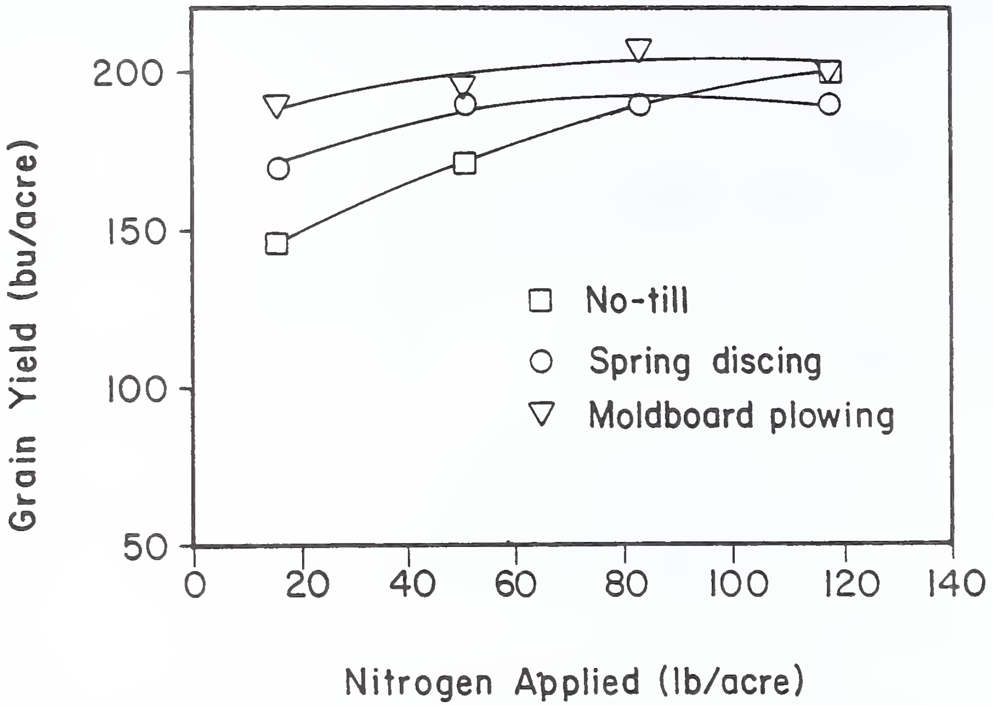

Figure 4. Effect of tillage system on corn response to nitrogen in a Udic Argiboroll soil, Staples, MN, 1987. Source: Moncrief et al. 1988.

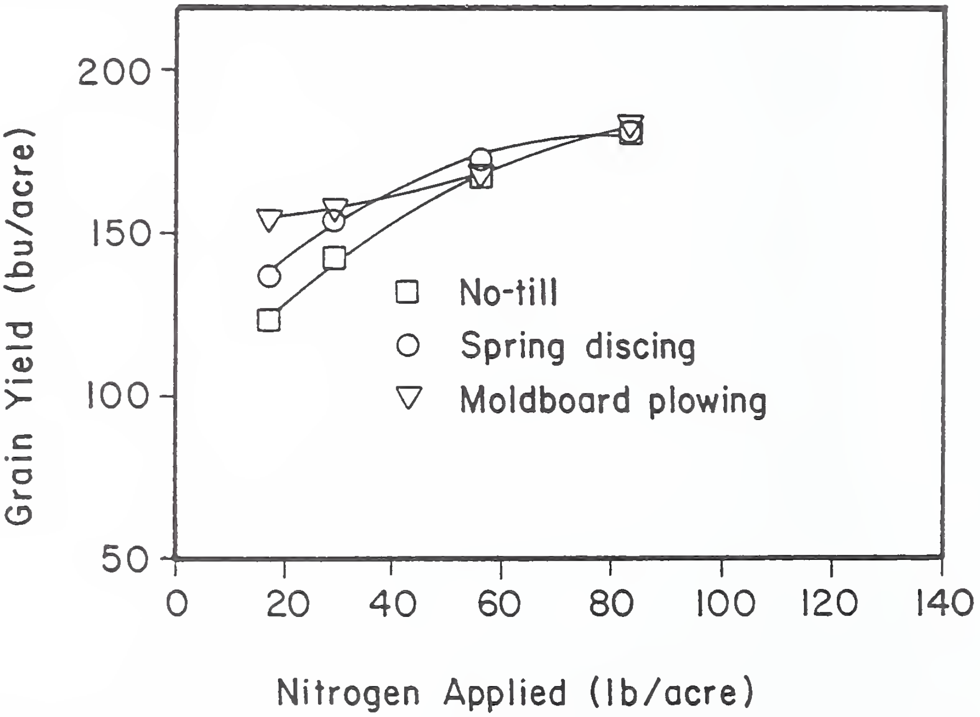

Figure 5. Effect of tillage system on corn response to nitrogen in a Udic Argiboroll soil, Staples, MN, 1990. Source: Moncrief et al. 1991.

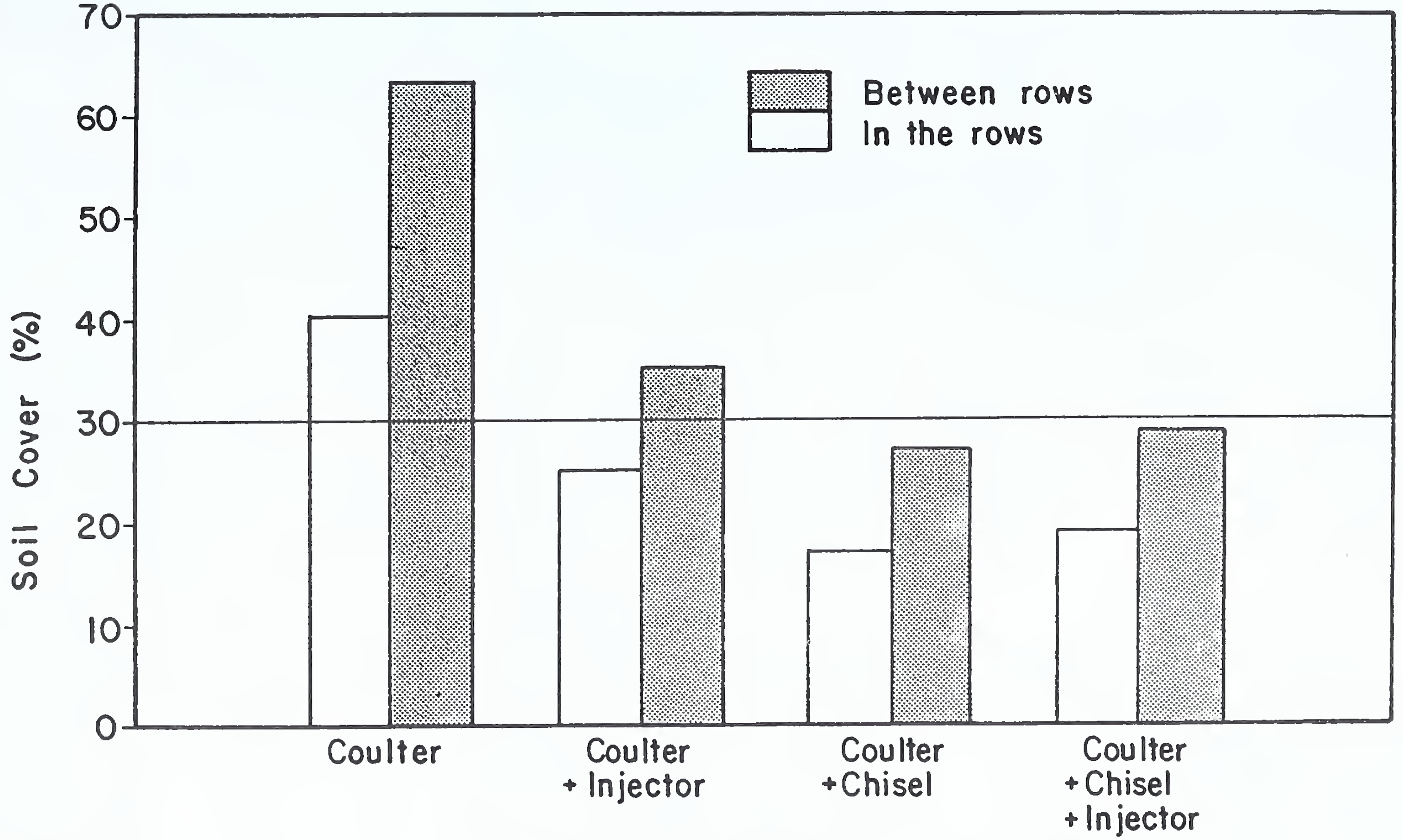

Figure 6. Effect of tillage equipment used in manure injection on corn residue cover. Source: Joshi 1991.

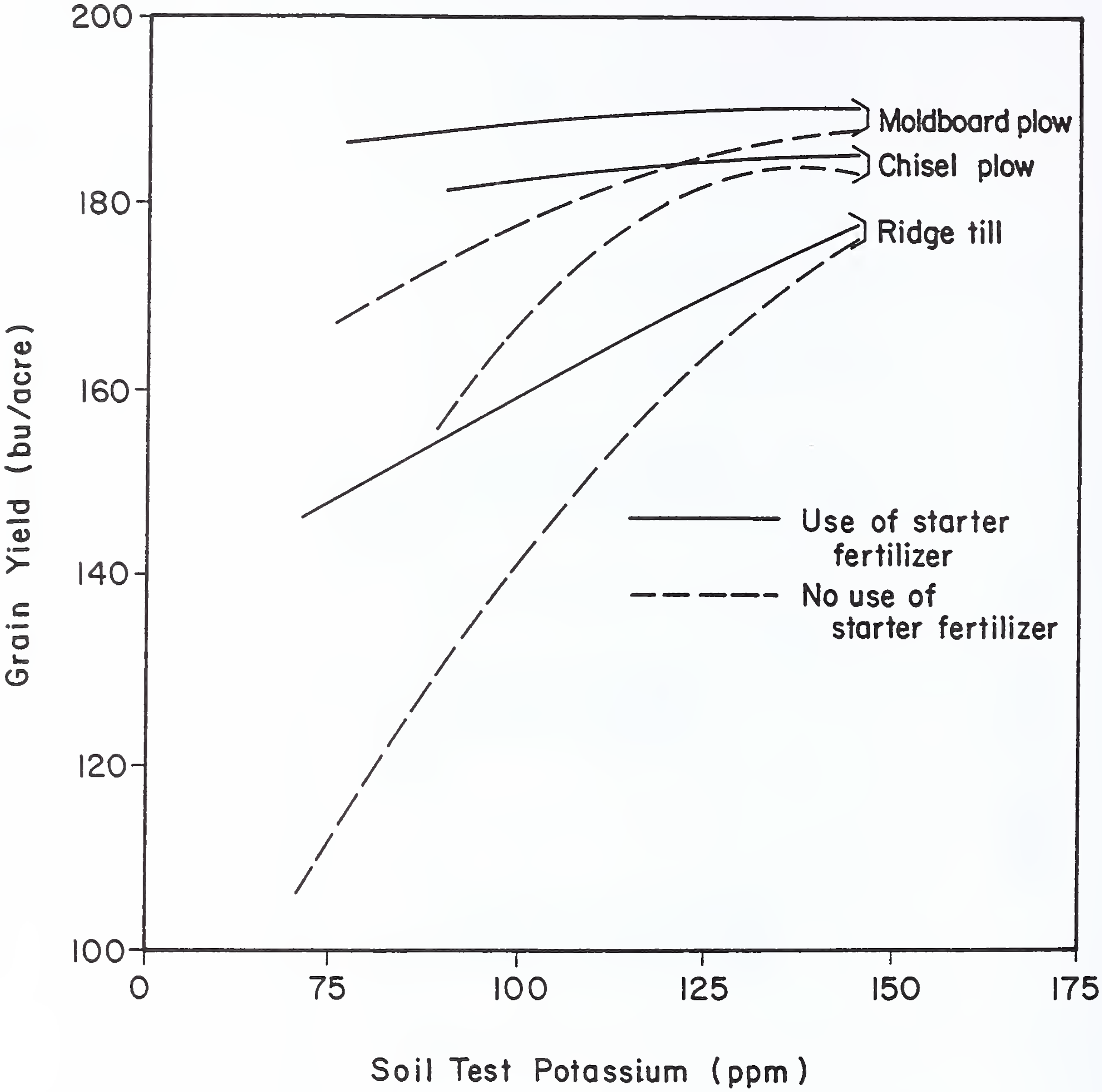

Figure 7. Effect of tillage on corn response to row-applied potassium and soil-test potassium. Source: Moncrief 1981.

9 Weed Management

Alex R. Martin

Weed control presents a challenge to successful crop production regardless of the tillage system. But, eliminating or reducing tillage affects weed management strategies and calls for new management skills. When spring tillage is eliminated, weeds often become established by planting time and must be controlled with herbicides.

The tillage system used affects the choice of herbicide. Different weed species prevail as tillage is reduced and they require different control programs. An understanding of the response of weed species to tillage systems is essential in designing effective weed management programs.

A weed management program must also be specific to the site and circumstances, so it is important to gather information when planning a program. Good sources of information include the Cooperative Extension Service, other conservation tillage operators, and product labels.

Weeds can be classified into groups based on their life cycles: winter annuals, summer annuals, biennials, and perennials. **Annual** weeds complete their life cycle in less than 1 year and reproduce only by seed. Summer annuals begin growth in the spring and complete their life cycle by fall. Winter annuals begin growth in the fall, and the following spring they flower, produce seed, and die. **Biennials** require more than 1 year but less than 2 years to complete their life cycle, and they reproduce from seed only. They germinate and grow during the summer, overwinter, flower, set seed, and die the following growing season. **Perennials** live indefinitely and reproduce both from vegetative structures—roots, rhizomes, and other vegetative parts—and from seed.

Tillage and Weed Growth

Tillage can either discourage or enhance weed growth. It can kill some weeds but may also stimulate subsequent germination of weed seeds. Annual weeds, particularly summer annuals, represent the majority of weed problems in row crops. They are well adapted to a tilled seedbed environment. Seed germination and seedling establishment increase when weed seeds are covered by a layer of mellow soil, as opposed to remaining on the soil surface. Compared to untilled soil, surface tillage such as disking creates a favorable environment for seed germination and increases the establishment of many annual weeds.

Tillage effectively controls established annual and biennial weeds, especially small plants. Destruction of top growth controls these plants because they are incapable of regenerating from roots. Perennial weeds can regenerate from portions of the root system or other vegetative structures, so tillage is less effective in controlling them, although it may somewhat reduce plant numbers and size.

The weed problems in most tilled seedbed systems are similar even though the number of tillage operations varies. Potential weed species differ between conventional tillage systems and systems without preplant tillage. Winter annual weeds—including downy brome, horseweed (marestail), prickly lettuce, mustards—and occasionally biennials may occur in ridge-till and no-till systems. These plants may be present at planting time. In tilled seedbed systems, they are not a problem because tillage destroys them and there is no late spring or early summer seed germination. Kochia, lambsquarters, Pennsylvania smartweed, and Russian thistle are early-spring-germinating summer annuals that begin to germinate before the soil is warm enough for corn to germinate. With no-till and ridge-till systems winter annuals and early-spring-germinating summer annual weeds represent an additional group of weeds to be dealt with.

It is important to understand the establishment, growth, and development patterns of weed species in order to develop effective weed management strategies. In no-till systems, certain weeds may be present prior to early spring herbicide applications, so a weed management program must control weeds that are established at planting time and weeds that develop later. This need to control established weeds represents an important difference from weed management in systems with tillage.

Mulch Tillage

Several systems leave 30 percent or more residue cover on the soil surface. Many of these involve a chisel plow, disk, or field cultivator followed by planting. One operation—chiseling or disking—may be performed in the fall, with a second operation—often field cultivating—performed in the spring. In order to maintain 30 percent residue cover, no more than two passes with a chisel, disk, or field cultivator are involved, depending on the amount of residue present. In general, one tillage operation is performed immediately before planting, eliminating all established vegetation. In this respect mulch-till is very similar to conventional systems because there are no established weeds at planting time. Annual and perennial weed growth under mulch tillage is similar to that under conventional tillage systems.

For maximum weed control in a two-pass tillage system, the operator should perform one operation early and the second as late as possible. The first operation plants weed seeds. The second operation kills the seedlings. For maximum effectiveness, one should delay the second operation until the soil warms and a major flush of seed germination occurs. This strategy is much more effective with sorghum and soybeans than corn due to the differences in optimum planting dates.

Mulch tillage may not be compatible with preplant-incorporated herbicides under some circumstances. Preemergence and postemergence herbicides, as well as the rotary hoe, are well suited to mulch tillage systems.

Crop residue on the soil surface intercepts preemergence herbicides as they are applied, but it also tends to suppress weed growth. Most common herbicides are not tied up by crop residue and will wash off with rainfall and move into the soil. The residue effect varies with the amount and type of residue and with the herbicide used.

Because heavy residue may interfere with herbicide incorporation, operators tend to till more than necessary when using preplant-incorporated herbicides. Soybean stubble and heavily grazed corn and sorghum stubbles do not need to be tilled before applying a preplant-incorporated herbicide. However, the residue must be evenly distributed over the soil surface and not windrowed. Spreaders on the combine help distribute residue. Heavy corn or sorghum residue may require tillage prior to herbicide incorporation. It is important to consider the number of tillage operations required when choosing a preplant-incorporated herbicide. Regardless of the implement used and the number of passes, good incorporation results only when the soil is dry enough and mellow enough to permit good mixing.

Ridge Till

Ridge till utilizes tillage and herbicides to control weeds. It is best adapted to row crops that can be ridged during cultivation. Instead of tilling the soil to prepare a seedbed, the previous year's ridges are left intact. The new crop is planted on top of the ridge remaining from the previous crop. The planter follows the old rows, and ridge-clearing sweeps or disks move soil, weed seed, and other crop residue out of the row and deposit them between rows where potential weeds can be controlled later with cultivation. Ridge till is particularly effective against annual grasses. Preemergence and postemergence herbicide applications, rotary hoeing, and cultivation can be used effectively in ridge-till systems. Normally a preemergence band application followed by cultivation is adequate.

Perennials, winter annuals, and early-germinating summer annual weeds may already be present by planting time, especially with soybeans and sorghum. Established weeds quickly remove moisture from the seedbed. Broadleaf weeds, including kochia, horseweed, prickly lettuce, Russian thistle, and various mustards can be a problem. It is a mistake to plant into large, uncontrolled weeds. Effective weed control through planting sets the stage for the rest of the season.

Weeds taller than 1 inch may not be eliminated by the planting operation. The problem is most serious along the shoulder of the ridge where larger, primarily broadleaf weeds may not be uprooted or covered by the ridge-clearing equipment. Large weeds growing close to the crop row may not be cut off by later cultivation. Because they have a head start on the crop, established weeds can provide severe competition.

Chemical and mechanical approaches are available for preplant weed control. Shallow disking controls weeds, but it destroys old ridges. This destruction causes the new crop row to be below the original surface, so some years the row may be cooler and wetter and result in slow crop emergence. Some producers use a mulch treader or a heavy roller harrow to control established weeds without destroying the ridge. Regardless of the preplant tillage used, weeds should be less than 1 inch tall for best success. Mechanical control of larger weeds requires more vigorous tillage, which destroys the ridge.

Chemical preplant weed control includes the use of preemergence and postemergence herbicides. Preemergence herbicides should be applied before appreciable weed growth occurs, usually by mid-April. Atrazine is often used where corn or sorghum is to be planted, and metribuzin or metribuzin plus chlorimuron ethyl are used where soybeans will be planted (table 8). These herbicides have the advantage of controlling small established weeds. Modest rates are sufficient because the objective is to control weed growth up to planting. Crop-oil concentrate or surfactant can be added to the spray mixture for increased postemergence activity. Because the planting operation moves most of the treated soil out of the crop row, little in-row effect remains. Postemergence approaches include the use of 2,4-D, dicamba, bromoxynil, or combinations for broadleaf weed control prior to corn or sorghum planting, and the use of 2,4-D prior to soybean planting. A waiting period is required between 2,4-D and dicamba application and sorghum planting to avoid crop injury. Paraquat or glyphosate can be used to control emerged annual grasses and broadleaf weeds prior to planting corn, sorghum, or soybeans. There is no waiting period required between paraquat or glyphosate application and planting.

When preemergence herbicides are used for preplant weed control, they should be applied while weeds are less than 2 inches tall, since small weeds are more readily controlled than larger weeds. If a postemergence application is required near planting time, it is best to treat before planting. If the application is made during planting, the operator should place the spray boom in front of the planter; displaced soil and crop residue may shield some weeds if the boom is behind the planter.

Effective preplant weed control programs set the stage for postplant control. After planting, mechanical and chemical weed control can be used in the same way they are used in tilled seedbeds.

No-Till

As originally defined, no-till involved no tillage, relied on herbicides for weed control, and accumulated crop residues on the surface. As discussed previously in the book, it provides benefits including wind and water erosion control, increased residual organic matter in the surface soil, and more efficient water use by crops. Innovative farmers grasped the concept but found the need to (1) knife in low-cost ammonia nitrogen, (2) keep new crop seedlings away from residues in continuous corn, (3) disrupt pans that restrict water penetration and root growth, and (4) till lightly after harvest to cover weed and grain seeds so they would germinate and could then be killed with one herbicide application. Utilizing limited tillage to satisfy these needs, the farmers were able to retain most of the erosion control benefits. The modified no-till systems are practically equivalent to no-till and the definition of no-till has been broadened to include them.

Many no-till planters use coulters in front of seed furrow openers. The planter can reduce weed control by displacing soil previously treated with residual herbicides. Straight or narrow ripple coulters cause minimal soil disturbance. Used at normal planting speeds, wider fluted coulters often throw soil from the row area. This displacement of herbicide-treated soil may allow weed growth in the crop row. The same is true of disk furrow openers set to remove soil from the crop row. So, one should not use wide fluted coulters and disk furrow openers after application of residual herbicides unless additional herbicide is banded at planting for in-row weed control.

Uniform distribution of crop residue is important in no-till. As mentioned, concentration of residue and weed seed interferes with the herbicide's reaching the soil and results in intense weed pressure in localized areas. To distribute residue, the operator should equip the combine with a chopper and a spreader. Distribution of residues over the entire soil surface is necessary for uniform herbicide application and performance.

The spray boom should clear standing residue but maintain 100 percent spray coverage. Weed control alternatives for no-till include preplant, planting time, and postplant herbicide applications.

Preplant Application

Preplant applications are made 5–30 days prior to planting. Preemergence herbicides should be applied 7–10 days prior to corn planting. The objective is to apply the preemergence herbicide before the germination of summer annual weeds, especially grasses. Certain preemergence herbicides are effective in controlling small, emerged broadleaf weeds but are somewhat less effective on emerged grasses. Weed seed germination is governed by soil temperature. The earliest germinating weed species are usually broadleaves, and summer annual grass seed usually germinates 7–15 days later. Operators ought to periodically scout fields beginning in late March or early April to monitor weed growth. Because emerged grasses are more difficult to remove, it is important to apply early preplant treatments without delay when summer annual grass seed begins to germinate.

Winter annuals, including field pennycress and other mustard species and horseweed (marestail), may be present in no-till fields before planting. To control these weeds, glyphosate or 2,4-D can be applied alone or in combination with a preemergence herbicide. After 2,4-D application, planting may need to be delayed to avoid crop injury. Product labels contain the appropriate time interval.

Rainfall must move preemergence herbicides into the soil prior to weed seed germination in order for them to be effective, and early application increases the likelihood of their receiving the required rain in time. Treatments are most effective if rain occurs within 7 days of application. Excessive rainfall may hasten herbicide dissipation and delay planting, reducing the duration of adequate weed control. Split herbicide applications counter these risks. Herbicides appropriate for early preplant use vary with location and conditions (consult Extension publications for more information).

When preemergence herbicides are not applied until soybean or sorghum planting, weeds of varying sizes are often present. In such instances, herbicide treatments must have postemergence activity. Some preemergence herbicides are not suitable for this situation.

The program for corn or sorghum is often developed around atrazine or cyanazine. Both of these herbicides are effective on many emerged annual broadleaf weeds and grass seedlings up to 1.5 inches tall, and they provide residual weed control. For soybeans, metribuzin plus chlorimuron ethyl and imazethapyr are examples of frequently used herbicides that also control small emerged weeds. Adding crop-oil concentrate, surfactant, or 28 percent nitrogen to the herbicide mixture increases the effect on emerged weed seedlings. The addition of 2,4-D improves broadleaf weed control. Alachlor, metolachlor, dimethenamid, acetochlor, and pendimethalin do not affect emerged weeds.

Application at Planting Time

Herbicides also may be applied during planting or after planting before crop emergence. Large weeds may be present if no preplant treatment was used, particularly by the time sorghum and soybeans are planted. If emerged grasses are taller than 1.5 inches, preemergence herbicides may not give consistent control and the operator must use a postemergence herbicide.

Paraquat and glyphosate are postemergence herbicides often used to control larger emerged weeds. They can be combined with a number of preemergence herbicides to remove emerged weeds and control later germinating weeds in no-till corn, sorghum, or soybeans. Extension publications and product labels contain possible herbicide combinations. Weeds established in the seedbed use soil moisture, and thus may limit crop germination and growth in years with low rainfall.

Postemergence Application

Postemergence herbicides can be utilized either as a part of a weed control program or as the total program. An approach relying entirely on postemergence herbicides involves controlling the flush of weeds prior to planting with glyphosate, either alone or with 2,4-D. Appropriate postemergence treatments can be used later for weed control in the crop. Such a program is well suited to narrow-row soybeans, where the quickly developing crop canopy compensates for the limited residual effect of most postemergence herbicides.

Another approach is to make an early preplant application of a preemergence herbicide, followed by a postemergence treatment in the growing crop. With this approach a reduced rate of the preemergence herbicide is often used since the objective is to keep the field clean only through planting. The postemergence treatment controls weeds that develop later.

Perennial Weed Management

Perennial weeds and volunteer trees may increase under no-till systems because there is no tillage to disrupt roots, rhizomes, and other vegetative reproductive structures. Perennial weeds and volunteer trees can be controlled with certain postemergence herbicides. Often the possiblity of crop injury limits the use of herbicides and therefore the control obtained. Undercutting with a v-blade can suppress trees while minimizing the negative aspects of tillage.

Perennial broadleaf weeds can be suppressed in corn or grain sorghum with directed postemergence applications of 2,4-D and dicamba. Johnsongrass and quackgrass can be controlled in corn and soybeans with postemergence herbicides. Fall applications of dicamba, 2,4-D, and glyphosate can be effective when used after crop harvest for perennial weeds that were not destroyed by the harvesting operation. Glyphosate can be used as a spot treatment or in a wiper applicator in soybeans or sorghum to control tall-growing perennials, including johnsongrass.

Cover Crop Management

Use is increasing of no-till row-crop planting into grass, legume sods, and cover crops. The established vegetation rapidly utilizes soil moisture—an asset during a wet spring. Under dry conditions the moisture a cover crop uses can cause problems with crop establishment. Soil moisture should be monitored. The vegetation should be killed when the soil moisture is optimal for planting. In wet areas and areas of high precipitation, vegetation should be left alive longer to dry the soil. In drier areas vegetation should be killed earlier in the spring to conserve moisture.

Grass or legume sod. Control of perennial forage grasses (including bluegrass, bromegrass, orchardgrass, tall fescue, and timothy) involves a fall treatment of glyphosate or a spring treatment of paraquat plus atrazine. If heavy pressure from annual grass is expected, a preemergence grass herbicide should be included in the spring. If the sod includes alfalfa or other legumes, include 2,4-D or dicamba with a fall glyphosate application or apply 2,4-D or dicamba in the fall before applying atrazine.

Pure stands of alfalfa, clover, and vetch can be economically controlled with 2,4-D or dicamba or a combination of the two. Control of established alfalfa with 2,4-D and dicamba is better if they are applied prior to rather than with or after most preemergence herbicides. Fall is the preferred time to control established sods. Herbicides are more effective as fall treatments, and fall treatments allow more time for soil residues of 2,4-D and dicamba to dissipate before spring planting. In the western portions of the North Central Region, the grasses may be drought stressed in the fall. In this case, herbicides will more completely kill the sod if applied in the spring or summer when the plants are growing more vigorously.

Rye, wheat, and other cereal grains. Cereal grain cover crops are usually allowed to grow until spring to provide winter cover and forage. If fall control is desired, the farmer should use moderate to full rates of atrazine or modest rates of glyphosate. A spring application of a preemergence herbicide is also in order, depending on the expected weed pressure.

For spring control of rye and other cereals, the farmer should use glyphosate or atrazine plus paraquat. Depending on expected weed problems, appropriate herbicides can be combined with the treatment used on the cover crop.

Table 8. Chemical names and trade names of herbicides mentioned in this chapter

Generic name	Trade name
Acetochlor	Harness, Surpass
Alachlor	Crop Star, Lasso, Micro Tech, Partner
Atrazine	AAtrex
Bromoxynil	Buctril
Cyanazine	Bladex
Dicamba	Banvel
Dimethenamid	Frontier
Glyphosate	Accord, Militia, Palado L, Ranger, Roundup, Shackle
Imazethapyr	Pursuit
Metolachlor	Dual, Medal, Pennant
Metribuzin	Lexone, Sencor
Metribuzin + chorimuron ethyl	Canopy, Preview
Paraquat	Gamoxone Extra
Pendimethalin	Prowl
2,4-D	2,4-D, Weedone, Weed-Rhap

10 Insect Management

Kevin Steffey, Mike Gray, and Rick Weinzierl

For years farmers and their advisers thought that a switch from plowing crop residues to leaving them on the soil surface would encourage the development of insect pest problems. Insect control guides fostered that belief; plowing was recommended as one method of controlling insects such as European corn borers. This concern about insects was one of several obstacles that prevented the more rapid adoption of crop residue management systems.

In truth, the switch from plowing to crop residue management systems has not led to dramatic increases in insect pest problems in the North Central states. Those who have adopted conservation tillage have learned this through experience. Although some insect problems and insect management practices are influenced by crop residues some years, effective management guidelines and tactics are available to control most insect pests, regardless of the tillage system employed. Extension entomologists throughout the North Central Region seldom alter insect management recommendations for different tillage systems.

Instead of regarding insect problems as an obstacle in crop residue systems, farmers are focusing their attention on insect management, as they should be. As more farmers implement crop residues practices, they need answers to the following questions:

- By leaving more crop residue on the soil surface, what different insect problems will I encounter?
- Will I need to improve my insect management program?
- How can I manage insects most cost effectively in reduced tillage systems?

This chapter provides an overview of the effects of tillage on insect pests, provides some detail about insects that are the subject of most farmers' questions, and offers specific suggestions for insect management in corn and soybeans grown in crop residue systems.

Effects of Tillage on Insect Management

Tillage practices may affect insects directly or indirectly. The type of system employed influences many soil parameters that directly affect insect survival, but especially temperature. The tillage system may also directly affect components of the farming system that, in turn, influence insect populations.

The development rates of insects are closely related to temperature. Insects that spend a portion of their life cycle in the soil may develop more slowly when crop residue reduces early season soil temperatures. For instance, initial emergence of corn rootworm adults is delayed in no-till cornfields. The tillage system may also influence insect survival during the winter. More corn rootworm eggs may survive during the winter in no-till systems than in plowed systems, especially if there is little snow cover and temperatures remain very cold.

An indirect effect of tillage on insect pests is the alteration of habitat from poor weed control. An increase in the densities of weeds that serve as hosts for insects such as black cutworms and stalk borers may increase the potential for crop damage. On the positive side, crop residue systems may also increase the impact of natural enemies on certain pests. In general, reducing tillage favors the survival of ground beetles, rove beetles, spiders, and ants, all of which include a number of generalist predators that feed on other insects.

As agricultural systems diversify, the interactions of insects and plants change. Some people argue that pest problems can be decreased by increasing the diversity of crops or other types of plants within a cultivated area. Even though greater diversity of species should add stability to agricultural systems and reduce the likelihood of pest outbreaks, it does not reduce pest problems in all situations.

Crop Rotations

Crop rotation has a greater influence on the potential for insect pest problems than tillage. The complex of insect pests changes according to the type of crops rotated, the sequence of the crop rotation, and the amount of time devoted to the production of one particular crop before planting a new crop. Farmers need to understand how cropping sequence affects insect populations, regardless of the tillage system employed. The briefs that follow explain the likelihood of an insect outbreak in different crop rotation schemes and offer insect management guidelines for each.

Corn After Soybeans

The potential for soil insect problems in corn after soybeans is generally low, even where corn is planted directly into no-till soybean stubble. Consequently, soil insecticides are rarely needed except for sporadic outbreaks of black cutworms.

A reasonable strategy for soil insect management is the use of an insecticide seed treatment and a scouting program beginning at plant emergence. A planter-box seed treatment of diazinon plus lindane protects the seed from seedcorn maggots, seedcorn beetles, and light infestations of wireworms. Because outbreaks of black cutworms are infrequent and sporadic, scouting for cutworms and applying a rescue treatment as needed is the preferred management strategy, regardless of the tillage system used. Unless grassy weeds have been difficult to control, crop residue systems do not encourage heightened problems with wireworms. Therefore, a planter-box seed treatment is sufficient to prevent damage in most fields. In fields where wireworms were seen or where conditions are conducive to wireworm activity (grassy weeds or cover crops), use bait stations to monitor their presence.

Corn After Corn

Corn rootworms are the primary soil insect pests in corn after corn. Rootworm damage is not any worse with crop residue systems than with conventional tillage systems. Insecticides labeled to control the larvae are recommended for corn after corn unless weekly rootworm beetle counts taken the preceding July and August did not exceed 0.75 per plant in corn after corn or 0.5 per plant in first-year corn.

Corn After Grass Sod

Corn planted after grass sod requires a high level of insect management. Several species of soil insects (wireworms, white grubs, sod webworms, billbugs, and cutworms) may threaten stands of corn planted after or into wheat, rye, bluegrass, brome, or fescue. If corn will be planted into grass sod that has been established for 2 or more years, consider applying a soil insecticide labeled for control of wireworms and white grubs.

Emerging corn that was planted directly into grass sod, rye, or wheat also may be attacked by foliage-feeding insects like armyworms, webworms, and stalk borers. After the grass is killed with herbicides, the larvae attack the young corn plants. With corn planted into grass, scouting for these pests and signs of injury is extremely important and should begin as soon as the corn emerges, even if a soil insecticide was applied at planting time. Soil insecticides do not control insects like armyworms and stalk borers that feed above ground.

Another insect management option for corn planted into a grass cover crop is application of an herbicide-insecticide preemergence spray immediately after planting. The local Cooperative Extension Service can recommend products appropriate for this type of application. Broadcast sprays of these insecticides control armyworms, cutworms, stalk borers, and some other foliage-feeding insects, but they are not effective against soil insects like wireworms and white grubs.

Corn After Clover or Alfalfa

Corn planted after alfalfa, clover, or an alfalfa-clover mixture in a crop residue system may be threatened by cutworms, grape colaspis, and seedcorn maggots. However, these soil insect pests have not been a widespread problem with this rotation.

Several cutworm species (black, claybacked, dingy, and variegated) may feed on corn planted into clover or alfalfa. Claybacked, dingy, and variegated cutworms overwinter as partially grown larvae and complete their development in the spring. Webworms also overwinter as partially grown larvae; the injury they cause in the spring may resemble that caused by cutworms.

Grape colaspis adults lay their eggs in clover in late summer. The eggs hatch and the grape colaspis overwinters as a partially grown larva. The larva resumes feeding in the spring on the roots of corn seedlings. Because the grape colaspis and some cutworms overwinter as partially grown larvae, their feeding activity begins in early spring.

Given the sporadic nature of these pests, a reasonable management strategy is to treat seed with diazinon to protect it from seedcorn maggots and to scout for cutworms and control them with an insecticide if economic thresholds are reached. The weakness of this strategy is that neither seed treatments nor rescue treatments control grape colaspis, and no soil insecticide is registered for control of grape colaspis.

Insect Pests of Corn

The insects most directly affected by changes in tillage practices are those which overwinter in the soil and become active during the spring. Soil-dwelling insects are affected more than foliage-feeding insects.

The soil insect complex in corn includes billbugs, corn rootworm larvae, cutworms, seedcorn beetles, seedcorn maggots, white grubs, and wireworms. Foliage-feeding insects include armyworms, European corn borers, hop vine borers, stalk borers, and stinkbugs. These insects are not unique to crop residue systems, but they are the ones most likely to be affected by changes in tillage practices. Scouting is extremely important for gathering information used to make sound insect management decisions.

Armyworms

No-till corn planted into rye, bluegrass, fescue pastures, old hay fields, and sod may be damaged by armyworms. Armyworms are less likely to cause serious damage in other crop residue systems. Armyworm moths lay their eggs in thick stands of grass in April and May. After herbicides kill the grasses, the larvae move to the seedling corn plants to feed, often causing severe damage.

Farmers should closely monitor fields for damage as soon as the corn plants emerge. Control measures are justified when 25 percent or more of the seedling plants are severely damaged, although the threshold may vary depending on the amount of defoliation and the stage of plant development.

Black Cutworms

Black cutworm moths migrating into the Corn Belt in the spring prefer to lay their eggs in weeds or unincorporated crop residues. If less tillage promotes increased densities of weeds before corn is planted, it increases the potential for infestations. Typically, the worms are a greater threat in southern areas of the Corn Belt.

Control of black cutworms can be justified when 3–5 percent of the corn seedlings are being cut or tunneled at or below the growing point. Black cutworms usually are controlled effectively with one of several available rescue insecticides.

Corn Rootworms

Western and northern corn rootworms are the primary soil insect pests of corn in the North Central Region. Damage is almost exclusively confined to fields where corn is planted after corn. The beetles lay their eggs in the soil in cornfields in late July and August and into early September. The eggs overwinter and the root-feeding larvae hatch in May and June.

Damage caused by rootworm larvae generally is no greater in conservation tillage systems than in plowed fields and has occasionally been less. Corn rootworm beetles have no preference for a particular tillage system when laying eggs. However, the beetles may emerge from the soil slightly later in the season in crop residue systems.

Cold, dry winters with little snow cover and low soil temperatures can cause high mortality of eggs near the soil surface. Occasionally these conditions cause greater mortality of eggs laid in plowed systems than in crop residue systems. However, the influence of tillage practices on the survival of the eggs differs from year to year.

The rootworm control practices and insecticides used for plowed corn are also generally used in no-till corn and other conservation tillage systems. Several soil insecticides are effective for controlling rootworm larvae in corn after corn and can be applied in any type of tillage system.

European Corn Borers

One to three generations of European corn borers occur each year throughout the North Central Region. In most areas, corn borers complete two generations. The larvae tunnel into the stalks, disrupting the flow of nutrients and water and reducing yields. Their tunneling also weakens stalks and ear shanks, sometimes resulting in broken stalks and dropped ears.

Tillage does influence populations of European corn borers primarily on an area-wide basis. Corn borers overwinter as mature larvae in cornstalks, so tillage practices that break up or bury cornstalks reduce survival of the larvae. As crop residue systems become more widespread, corn borer populations will probably increase, although factors other than tillage also regulate their numbers. The impact of tillage is not confined to a single field, however, because corn borer moths are very mobile and fly from field to field during egg laying.

Most states in the North Central Region offer worksheets that help farmers to estimate their expected yield, anticipated price for the corn, and cost of control in order to make informed decisions about controlling corn borers.

Slugs

Although they are not insects, slugs can be economically important pests of corn and soybeans in no-till fields, particularly during wet springs. Crop residues provide a food source for slugs and help maintain cool, moist conditions that favor slug survival. They usually feed on the lower part of the plant, eating partly or completely through the leaves and leaving ragged holes. Slugs usually cause fewer problems in mulch-till systems than in other conservation tillage systems.

Managing slugs is difficult. Reliable treatment thresholds have not been developed, and effective treatments are not readily available. A decision to manage slugs depends on the amount of stand loss and the level of defoliation. Some formulated baits are registered for slug control, but suggested broadcast application rates are expensive. Row banding the baits reduces the cost, but this type of application is difficult.

Stalk Borers

Stalk borers are more numerous in areas where grassy weeds or forage grasses remain standing from the previous season. In the spring the insect feeds within those grasses (where eggs were deposited the previous August and September) until it outgrows them or until the weeds are killed by herbicides. The stalk borer then moves into corn. Where crop residue systems allow the persistence of grassy weeds from one season to the next, stalk borers can cause severe damage.

Some preemergence treatments are effective if one anticipates an infestation. Rescue treatments are not effective after the stalk borers tunnel into the corn plants. Ideally, postemergence sprays should be applied when larvae are moving from their initial weed hosts to young corn plants. Timing this event is critical. The best method for reducing the potential for stalk borer damage is a good weed control program that eliminates suitable egg-laying sites within or next to a field.

Insect Pests of Soybeans

Throughout most of the Corn Belt, insect pests sporadically attack soybeans. The primary foliage-feeding insects are bean leaf beetles, grasshoppers, green cloverworms, Japanese beetles, Mexican bean beetles, potato leafhoppers, and stinkbugs. Two pests that are not insects—twospotted spider mites and slugs—occasionally cause significant injury. The soil insect complex includes cutworms, seedcorn maggots, and white grubs.

Although the effects of different tillage practices on pests in soybeans should be considered when planning an insect management program, management strategies need not be altered in most situations. Regardless of the tillage practice employed, foliage-feeding insects should be monitored regularly throughout the season. Established economic thresholds are available for defoliating insects. With the exception of seedcorn maggots and, occasionally, white grubs, soil insects rarely cause economic damage to soybeans.

Bean Leaf Beetle

Bean leaf beetles overwinter as adults under debris in protected sites. They emerge early in the spring, before soybeans are planted, and move into fields of alfalfa and clover. As soon as the soybeans emerge, the beetles abandon the alfalfa and clover fields to move into soybeans. They feed on emerging cotyledons and young leaves, sometimes reducing plant populations. Eggs are laid in the soil, and the larvae feed on root nodules. The beetles that emerge later in the summer feed on the foliage and pods.

Bean leaf beetle injury is usually greatest in the earliest planted fields. If crop residue keeps the soil cooler and wetter and soybeans are planted later, the potential for damage declines. An early season treatment for injury may be justified if 20 percent of the plants are cut and the stand has gaps of 1 foot or more, or if at least one seedling per foot of row is destroyed.

Grasshoppers

Grasshopper populations vary from year to year and are regulated primarily by weather, natural enemies, and fungal diseases, although tillage can also affect them. Crop damage is likely to be greatest during years when dry weather prevails. Grasshoppers can also damage corn, wheat, and other crops.

Most grasshopper species deposit egg pods in the soil in uncultivated field margins, roadsides, ditchbanks, fencerows, pastures, and alfalfa and clover fields in late summer and early fall. The eggs overwinter and hatch from late May through July. Grasshopper nymphs usually feed for 2–3 weeks near their hatching site. When their food source becomes scarce or when feeding sites are mowed or otherwise destroyed, the nymphs move to nearby crops where they feed and become adults. There is generally one generation of each species of grasshopper each year.

Three of the most common species in the Corn Belt are the differential, migratory, and redlegged grasshoppers. The differential grasshopper lays eggs in sod and weedy ground bordering the crop upon which it feeds. The migratory grasshopper lays its eggs throughout grain and other crops or in idle land grown up to weeds. The redlegged grasshopper tends to lay eggs throughout fields and cropland, especially in open fields. Migratory and redlegged grasshoppers can damage no-till soybeans or corn planted into cover crops. Grasshoppers may also injure soybeans double-cropped directly into wheat stubble, especially during drought.

Performing tillage operations in the spring before the eggs hatch helps control grasshoppers by destroying egg pods. Farmers should be alert for grasshopper damage early in the season in fields of soybeans or corn that are no-tilled into cover crops. Grasshoppers need control measures when they become noticeably abundant and while they are small. An infestation of 10 or more nymphs per yd^2 in soybeans or corn may justify treatment.

Seedcorn Maggot

Seedcorn maggot adults (flies) emerge early in the season and seek decaying organic matter on which to lay their eggs. The larvae (maggots) feed on the seeds and underground portions of soybean seedlings. Heavy infestations may significantly reduce plant populations. The potential for damage by seedcorn maggots increases if green cover crops and crop residues are incorporated into the soil. Applications of liquid animal waste or solid manure also increase the incidence of problems in some states. A planter-box seed treatment of diazinon protects the seed from attack.

General Pointers

Although the potential for insect pest problems is slightly greater in conservation tillage systems than in conventional systems, adequate management guidelines and control tactics are available. An efficient and economic insect management program must include

- an understanding of the relationship between crop rotation and insect biology,
- consideration of soil insecticides and seed treatments,
- proper selection and placement of soil insecticides in corn,
- effective weed control,

- regular monitoring or scouting programs in each field and maintenance of detailed records and field histories,

- an understanding of up-to-date economic thresholds and treatment guidelines, and

- timely insecticide applications, when necessary.

Adherence to these management tips will ensure that insect pests pose no more of a threat in management systems where crop residues are left on the soil surface than in systems where residues are plowed under.

11 Disease Management

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The potential severity of several important crop diseases may be affected by the type of tillage system. In conservation tillage systems, diseases are frequently more of a risk if they are favored by wet soils or low soil temperatures or if they can spread from infected crop residues on soil surfaces. Diseases that are favored by hot, dry soils are usually less of a risk in conservation tillage systems.

For diseases that may be more severe with conservation tillage systems, the selection of appropriate disease management practices becomes important. A conservation tillage system may itself serve as a viable disease management practice for crop diseases that are less severe with lower soil temperatures or increased soil moisture. Knowledge of the diseases affected by conservation tillage practices, coupled with the history of disease in each field, is important when selecting effective disease management practices.

Disease management practices include selection of resistant cultivars, crop rotation, date of planting, crop fertility program, fungicide usage, insect control, and weed control, along with sound agronomic practices. The number and combination of these practices necessary vary from disease to disease.

Disease Development

Every agricultural crop is subject to several diseases, and each disease has a specific set of conditions that favors its occurrence and severity. Diseases are variable from year to year, region to region, field to field, and even within a field. Some level of disease occurs in every field each year. However, by selecting proper disease management strategies, diseases should rarely become economically damaging.

Pathogens include many species of fungi, bacteria (including mycoplasmas and spiroplasmas), viruses, and nematodes. Disease development is dependent on three factors: (1) susceptibility of the cultivar, (2) presence of a virulent pathogen, and (3) environmental conditions favorable for infection and the spread of disease. The most critical environmental factors include air and soil temperatures, soil moisture, frequency or amounts of rainfall, relative humidity, soil type, and with certain diseases, soil pH and fertility. Most viruses and a few bacteria require a vector—an insect, a fungus, a nematode, or another organism—in order to move from plant to plant or field to field. The population and activity of any given vector depends on factors similar to those affecting disease development.

When all three factors—host, pathogen, and environmental conditions—occur at the right time and in the right combination, a disease occurs. If these factors remain favorable for an extended period of time, the disease becomes severe. If one or more of these factors is unfavorable, the disease does not develop to damaging proportions. Thus, disease management practices aim at eliminating, reducing, or altering one or more of these factors.

The major crop diseases in the North Central Region fall into five categories: (1) seed rots and seedling blights, (2) root and stem diseases, (3) foliar diseases, (4) seed diseases, and (5) systemic diseases.

Seed Rots and Seedling Blights

Seed rots and seedling blights are more likely to occur when soil or environmental conditions are unfavorable for rapid seed germination or seedling development or both. These diseases are exacerbated by low-quality seed, plant damage from chemicals or fertilizers as opposed to chemical or fertilizer stress, insect damage, and poor seed-soil contact. Some cultivars are more susceptible to these rots and blights because they are inherently slow germinators. In general, seed rots and seedling blights are most damaging when soils are cold and wet, and they may increase in conservation tillage systems. Pythium seedling blight of corn and Phytophthora root rot of soybeans are two diseases that may be more severe with conservation tillage systems if appropriate measures are not taken. However, a few diseases, such as charcoal seedling blight of soybeans and Fusarium seedling blight of corn, are more damaging with hot, dry soils and may be reduced by certain conservation tillage systems.

The following management practices reduce the incidence and severity of seed rots and seedling blights in conservation tillage systems:

1. Use of high-quality, vigorous, disease-free seed of an adapted cultivar.
2. Selection of disease-resistant cultivars.
3. Planting at the proper depth, with the proper spacing, and at a time when soil temperatures and moisture are favorable for rapid germination.
4. Use of the fungicide metalaxyl as a seed or soil treatment. The fungicide can often control Pythium and Phytophthora seedling diseases in corn and soybean cultivars that are planted early or in wet soil and that have poor resistance. Other seed-treatment fungicides are available for specific situations or for fields that have a history of certain diseases.

5. Avoidance of seedling stress from soil compaction or inappropriate levels of herbicides and fertilizers or other chemicals.

Root and Stem Diseases

Root and stem diseases commonly occur throughout the North Central Region and occasionally result in substantial yield losses. The most important root and stem diseases of corn and sorghum are the various stalk rot diseases—anthracnose, Gibberella, Fusarium, and Diplodia. Sorghum downy mildew can be a significant problem on sorghum in some western areas of the region.

The major root and stem diseases of soybeans include soybean cyst nematode, Phytophthora root rot, Rhizoctonia root rot, brown stem rot, and charcoal rot. The most significant root and stem diseases of wheat include take-all, common root rot, and foot rot.

Nearly all of these diseases may be more severe when the same crop is planted 2 or more successive years. Conservation tillage practices, when combined with continuous cropping, favor the development of any disease in which the pathogen survives in crop residues. Where a pathogen does survive, significant root or stem disease may take hold unless disease management practices are utilized.

However, conservation tillage, when combined with crop rotation, can actually reduce certain cornstalk rots and charcoal rot of soybeans. In the Northern Great Plains, for instance, sorghum is rotated with wheat in a system known as ecofallow. This is a system of controlling weeds and conserving water in a crop rotation, with minimal disturbance of crop residue and soil. The increase in available soil moisture greatly limits the development of stalk rot. Common root rot caused by *Bipolaris* spp. is less severe with conservation tillage than with conventional tillage.

Phytophthora root rot of soybeans is not affected as much by crop rotation as it is by tillage system. It is more severe with no-till than ridge till, with ridge till than chisel plow, and with chisel plow than moldboard plow, regardless of crop rotation.

Conservation tillage has no direct effect on yield losses due to the soybean cyst nematode. However, interaction of the soybean cyst nematode with diseases such as charcoal rot creates greater losses than either disease would inflict individually. Conservation tillage systems can limit the effects of this disease complex by conserving soil moisture and reducing soil temperatures, two conditions that reduce losses from charcoal rot.

The following management practices reduce the incidence and severity of root and stem diseases in conservation tillage systems:

1. Use of crop rotation. Long rotations are considerably more effective than a single year between the same crop.

2. Use of resistant cultivars, selection of corn hybrids that have good stalk strength to reduce lodging, and selection of hybrids with resistance to leaf blight diseases, since leaf blight stress can increase the incidence and severity of stalk rots. Full-season corn hybrids are generally more resistant to stalk rots than short-season hybrids.

   No soybean cultivars are known to be resistant to Rhizoctonia root rot, charcoal rot, or Fusarium root rot. The two types of resistance available for Phytophthora root rot are race-specific resistance and rate-reducing resistance (field tolerance). Resistant cultivars are available for brown stem rot of soybeans. Tolerant varieties are available for take-all and common root rot of wheat.

3. Avoidance of nutrient deficiencies or excesses, which stress plants and increase susceptibility to certain root and stem diseases. For example, stalk rots may be more severe when the nitrogen-potash ratio is overbalanced in favor of nitrogen.

4. Taking care not to exceed the number of plants recommended for a particular cultivar or for the soil moisture available.

5. Control of insects such as rootworms and corn borers.

6. As much as possible, reduction of stress-producing factors, such as soil compaction, nutrient deficiencies, herbicide stress, weeds, and adverse soil pH.

7. Proper harvesting. If more than 10–15 percent of the plants in a field show cornstalk rots, harvest as early as possible to avoid lodging. Drying costs seldom exceed yield losses from lodging.

Foliar Diseases

Numerous foliar diseases occur in crops of the North Central Region. Foliar diseases are potentially more damaging in corn, sorghum, and wheat than they are in soybeans. The more significant and most commonly encountered foliar diseases of corn include anthracnose, southern corn leaf blight, northern corn leaf blight, gray leaf spot, eyespot, Stewart's bacterial leaf blight, common rust, and southern rust. In the western areas of the region, Goss's bacterial wilt and blight may also occur.

Common fungal diseases in the grain-sorghum-producing areas include sooty strip, leaf blight, and rust. Bacterial stripe and bacterial streak are also common.

The major foliar diseases of wheat are Septoria leaf blotch complex, Septoria glume blotch, powdery mildew, leaf rust, and tan spot.

In soybeans common foliar diseases include bacterial blight, bacterial pustule, brown spot, downy mildew, and Cercospora blight.

Pathogens of all these diseases readily survive in infected crop residues, except for the rust diseases and Stewart's bacterial leaf blight. Tillage systems have little or no effect on disease development, except where the same crop is grown for 2 or more successive years and infected crop residues are left on the soil surface. In such instances significant foliar disease may occur.

The following practices reduce the incidence and severity of foliar diseases in conservation tillage systems:

1. Use of crop rotation. This practice is especially important if conservation tillage is used in conjunction with continuous cropping, when the previous crop was diseased, and if good genetic resistance to the disease is not available in adapted cultivars.

2. Use of resistant or tolerant cultivars.

3. Planting of winter wheat after the fly-free date, and planting of spring wheat at the earliest suitable date.

4. Adopting a balanced fertility program based on soil tests. Excessive rates of nitrogen often increase disease severity, especially in wheat.

5. Use of foliar fungicides in susceptible varieties of wheat has been economical in those years when weather conditions favor the development and spread of disease. Foliar fungicides are very rarely economical in controlling disease in corn and soybeans, except in seed production fields.

Seed Diseases

Some important and commonly encountered ear diseases of corn in the North Central Region are Gibberella ear rot, Fusarium ear rot, and Diplodia ear rot. These are caused by the same pathogens that cause stalk rots of corn. Several ear rot fungi may produce mycotoxins in infected kernels, an occurrence that is perhaps more important than the yield losses they cause. The most notable mycotoxins are aflatoxin, produced by *Aspergillus flavus,* vomitoxin and zearalenone produced by *Gibberella zeae* or *Fusarium graminearum*, and fumonisin produced by *Fusarium moniliforme*. Gibberella, Diplodia, and, to some extent, Fusarium ear rots are potentially more severe where corn follows corn and infected crop residues are left on the soil surface. Consequently, these diseases may be affected by tillage in continuous-corn fields, and appropriate disease management practices should be utilized with conservation tillage systems.

The two most common seed diseases of soybeans in the North Central Region are pod and stem blight complex and purple seed stain, with the pod and stem blight complex being more important. Both diseases may be seed borne. Both may be more severe where soybeans follow soybeans and infected crop residues are left on the soil surface.

The most common diseases affecting wheat heads in the region are scab and Septoria glume blotch. They can cause significant losses in yield and grain quality when extended periods of wet, humid weather occur during or after heading. Conservation tillage systems have little effect, if any, on the development of these diseases, except in cases where wheat follows wheat or other small grains. Scab may be more severe where wheat follows corn and corn residues on the soil surface were affected by Gibberella stalk rot or Gibberella ear rot.

Disease management practices that reduce losses from seed diseases in conservation tillage systems include the following:

1. Crop rotation is important with conservation tillage. This practice is especially important if the previous crop was diseased and if genetically resistant cultivars are not available.

2. Selection of resistant cultivars, especially in fields cropped to the same crop.

3. Maintanence of adequate and balanced soil fertility levels, based on soil tests.

4. Control of insects such as corn ear worms.

5. Harvesting promptly. If ear rots are present, producers should dry grain as rapidly as possible to 14 percent moisture to prevent further development of disease or production of mycotoxins. Grain infected by Gibberella, Fusarium, or Aspergillus may contain mycotoxins that cause feeding difficulties in certain animals.

Systemic Diseases

Systemic diseases primarily include the virus diseases. Virus diseases of corn in the North Central Region comprise maize dwarf mosaic, maize chlorotic dwarf mosaic, and wheat streak. Corn lethal necrosis, found only in Kansas and Nebraska, is a synergistic interaction between the maize chlorotic mottle virus and either the maize dwarf mosaic virus or the wheat streak mosaic virus.

The only important virus disease of sorghum in the region is maize dwarf mosaic virus.

Several virus diseases can affect soybeans, but generally they cause only minor losses. The more common include bean pod mottle, soybean mosaic, bud blight, and soybean chlorotic mottle.

Virus diseases of wheat are common. They include barley yellow dwarf, wheat yellow mosaic (formerly wheat spindle streak mosaic), wheat soil-borne mosaic, and wheat streak mosaic. All wheat virus diseases, with the possible exception of wheat yellow mosaic, can cause significant yield losses in susceptible cultivars.

Virus diseases require vectors—aphids, leafhoppers, mites, fungi, or thrips—to spread efficiently. Tillage systems per se have no effect on the development of virus diseases, but it is important to control reservoirs of the viruses (such as rhizome johnsongrass) and their vectors.

Disease management practices that reduce losses in conservation tillage systems include the following:

1. Selection of cultivars with resistance or tolerance to the virus diseases.

2. Control of volunteer hosts of viruses—crops and weeds—in and around fields of susceptible crops.

3. Planting winter wheat after the fly-free date, and planting spring wheat at the earliest suitable date. Virus vectors are more active in warmer conditions, and virus infections early in the growing season are much more damaging than infections later in the season.

4. Chemical control of virus vectors is usually not economical except in highly specialized situations.

12 Erosion Control With Sparse Residue

John M. Laflen and Glenn A. Weesies

A number of important crops produce little residue, including soybeans, sunflowers, cotton, and many vegetables. Soybeans and sunflowers are widely produced in the North Central Region, and much of the region's wind and water erosion occurs on land where they grow.

Soil erosion is greatly affected by the amount of residue cover, how recently the land was tilled, and the amount of buried biomass. While buried biomass, including roots and residue buried by tillage, can significantly reduce soil erosion, its impact is usually less than that of surface crop residue. Long-term crop production without tillage can reduce soil erosion by more than 50 percent just by consolidating the soil surface.

The relationship between the level of residue cover and reductions in soil erosion is shown in figure 8. The figure illustrates the positive correlation between the amount of surface residue and the reduction in soil erosion and shows that even a little residue reduces soil erosion. One could reasonably interpret the figure as indicating that a reduction of residue cover from tillage would be particularly critical for low-residue crops. Because such crops do not leave that much residue to begin with, any tillage reduces the residue to an even lower level. Fragile residue, like soybean residue, looks like a high percentage to begin with, but any tillage—even planting activity—greatly reduces it (tables 9 and 10).

Table 9 shows typical amounts of residue cover left after various tillage operations in corn and soybeans in several Iowa studies. The residue left after harvesting soybeans was 83 percent and that left after harvesting corn was 93 percent. Both levels gave very good erosion control compared to bare soil.

However, when tillage was performed in the fall or the spring, residue covers drastically decreased for soybeans. For example, soybean residue cover decreased to 15 percent with fall chisel plowing, compared to corn residue, which fell to 49 percent. Spring disking left slightly higher residue covers both in soybeans (18 percent) and corn (56 percent). Compared to moldboard plowing, both fall chisel plowing and spring disking systems after soybeans gave about a 40-percent reduction in soil erosion immediately after planting, but the reduction after corn was more than double that amount—about 80 percent. While the reductions are substantial for soybeans, tillage after planting can diminish any reductions in soil erosion achieved from conservation tillage systems.

In many fields initial erosion control achieved from surface residues is satisfactory. However, later in the season—June and July—the residue cover decreases (table 10).

Almost every field operation buries at least some residue. Part of the reason for the wide variation in percentages in table 9 is differences in tillage operations. Application of anhydrous ammonia is common in the North Central Region for corn following soybeans, and the equipment used buries from 10 to 40 percent of the soybean residues. By eliminating nitrogen fertilizer following soybeans or by delaying fertilization tillage near lay-by in the following corn crop, producers would leave more crop residue for a longer period and would substantially reduce erosion on highly erodible land.

Other than for soybeans, few data are available for crops that produce little residue. Residue covers remaining after harvesting sunflowers have been measured at about 60 percent. Decomposition rates of sunflower residues are similar to those for soybeans, and sunflower residues seem to be quite fragile. Based on these limited observations, Colvin et al. (1981) concluded that the erosion occurring in crops grown after sunflowers would be slightly greater than that taking place after soybeans. This conclusion suggests that farming operations for crops produced after sunflowers should be severely reduced in areas where sunflowers are grown on highly erodible land.

In areas where water is adequate, residue from killed winter cover crops can be an important source of soil erosion protection before and after planting. Since few data have been collected, there has been little evaluation of these residues in the North Central Region.

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Table 9. Percentage of soybean and corn residue cover remaining after harvest in different tillage operations in Iowa

Crop and type of operation	Percentage of residue cover remaining: Average	Percentage of residue cover remaining: Range	Erosion reduction (compared to fall moldboard plowing)
Harvest			
Soybeans	83	58–98	*
Corn	93	85–99	*
Fall moldboard plowing			
Soybeans	2	2–3	*
Corn	9	5–12	*
Fall chisel plowing			
Soybeans	15	10–24	37
Corn	49	33–59	75
Spring disking			
Soybeans	18	14–21	43
Corn	56	41–71	81
No-till			
Soybeans	58	35–92	86
Corn	86	74–98	93

* Data not obtained.

Source: Colvin et al. 1980.

Table 10. Percentage of soybean and corn residue cover remaining in mid-June and mid-July after different tillage operations in Iowa

Crop and type of operation	Percentage of residue cover remaining: Mid-June	Percentage of residue cover remaining: Mid-July
Spring moldboard plowing		
Soybeans	2	10
Corn	6	15
Spring chisel plowing		
Soybeans	11	11
Corn	30	28
No-till		
Soybeans	37	21
Corn	56	45

Source: Laflen and Colvin 1982.

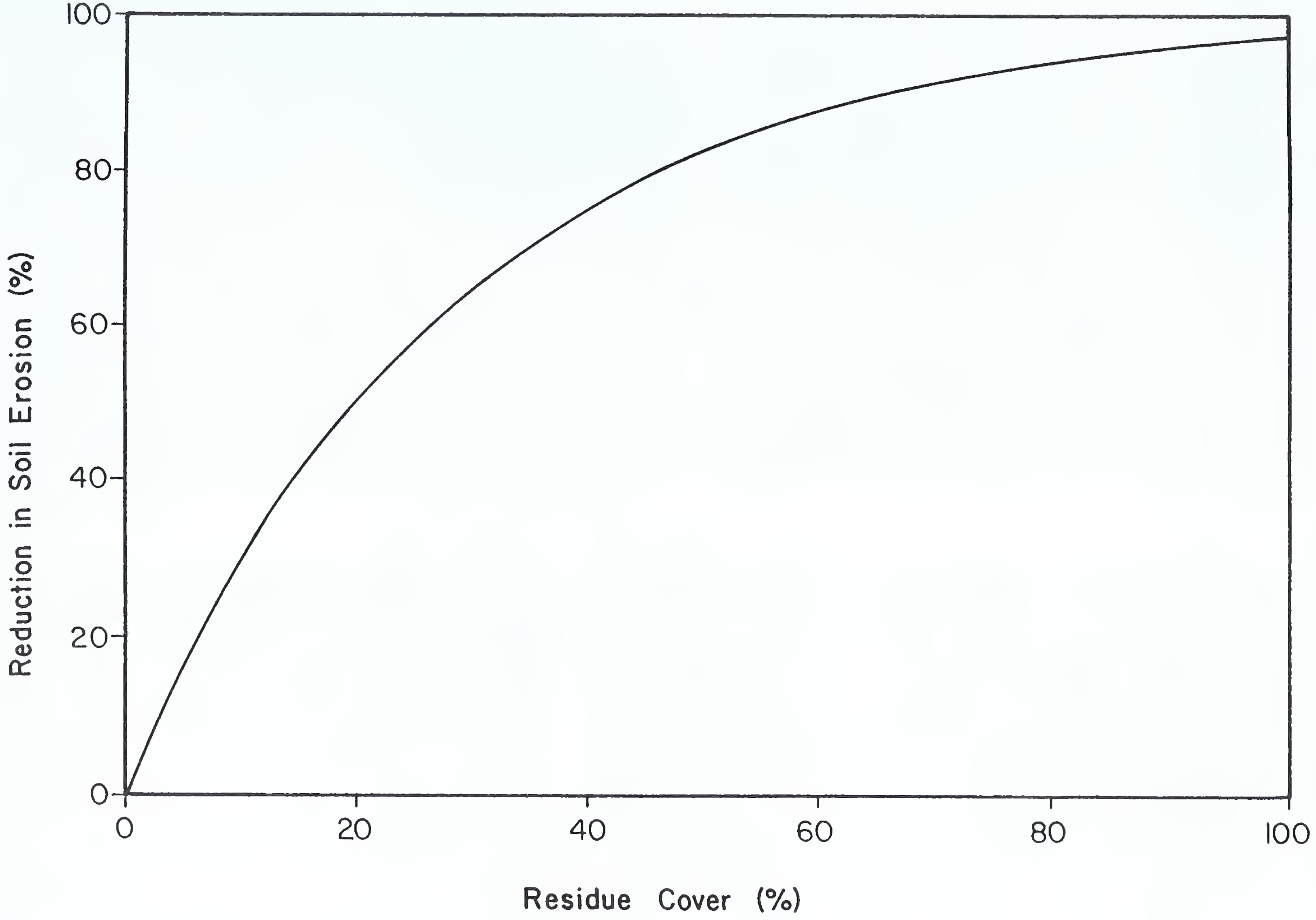

Figure 8. Predicted effect of residue cover on soil erosion. Source: Laflen et al. 1985.

13 Effects of Crop Residue Management on Water Quality

Stewart W. Melvin

Water quality related to crop production systems usually refers to the quality of nonpoint water (surface water and groundwater) associated with the areal effects of agricultural management techniques. In the North Central Region, the most predominant surface-water quality problem is sediment. Farmers use conservation tillage as the first line of defense to control sediment and to meet conservation goals for curbing soil erosion.

Many equate the prevention of soil erosion with the protection of water quality, but this relationship is being debated. Not all water quality problems are associated with sediment in surface water. Pollutants affect water resources in other ways, as a breakdown of the hydrologic cycle reveals.

The Hydrologic Cycle

The hydrologic cycle of any particular area can be described as an accounting system for the water movement through it. Figure 9 illustrates the annual water balance on a typical field in the North Central Region managed with a conventional tillage system. Of the 30–36 inches of annual precipitation, 26–32 inches infiltrate the soil and 3–4 inches run off the surface. The total water lost as evapotranspiration is 20–24 inches. The remaining excess water (2–3 inches) either supplies base stream flow via springs or seepage faces or replenishes deep groundwater.

Chemicals are transported from the field in water and sediment. Therefore, if one minimizes sediment losses, one also controls chemicals that move by way of sediment. Chemicals that are not attached to soil particles are transported primarily by moving water. Those which have little or no attraction to soil particles tend to move into the soil profile with rainfall and may be transported off-site with shallow groundwater. Chemicals that are slightly bound to soil particles tend to stay near the surface and move primarily with surface runoff. Given such variations, it is difficult to determine the effects of conservation tillage on water quality without knowing the effects of the management system on the hydrologic cycle, the chemical properties of the product used, and the whether the primary concern is with surface water or groundwater.

Conservation tillage influences infiltration, surface runoff, and evapotranspiration, and as a result, it can significantly alter the hydrology of the field. In general, conservation tillage increases infiltration and decreases surface runoff and evapotranspiration, so more water moves through the profile as shallow groundwater discharge. Conservation tillage can also have other impacts. It increases residue covers, while minimizing chemical incorporation into the soil. The use of postemergence herbicides generally increases with most conservation tillage systems.

Chemical Properties

An important consideration in determining the effect of conservation tillage on water quality is the interrelationship of chemicals with soil, plants, and water. The three major characteristics that affect the fate of any chemical are adsorption, solubility, and persistence.

Adsorption

Adsorption in this context describes the tendency of a chemical to bind to soil particles. Most highly adsorbed chemicals attach either to clay particles or the organic matter in soil. The measure of this ability to attach is the adsorption coefficient, K. This value is the ratio of the chemical concentration in soil to the concentration in water. K values can range from less than 0.1 to more than 1,000. The higher the K value, the more strongly the chemical is attracted to soil particles. Chemicals with high K values tend to stay in the location where they are applied and move only with soil erosion. A low K value describes a chemical that is not attracted to soil particles and is more usually found in water solution.

Solubility

Water-soluble chemicals readily mix with water and remain in solution. They are more likely to move with water, and they are more prone to leaching if their K values are low. Solubility is measured by the quantity of material dissolved in a standard amount of water. One of the most common highly soluble, nonadsorbed chemicals is nitrate. Chemicals that leach readily may cause (1) environmental damage, (2) loss of the chemical and its function, which translates to financial loss, (3) reduced yields, and (4) energy loss, from loss of the product, which was created through the use of energy.

Persistence

Chemicals decompose from chemical, biological, or photochemical processes. A chemical that decomposes by sunlight or that is likely to evaporate must be incorporated into the soil to conserve the product and protect the environment. Environmentally speaking, low-persistence products are preferable, although a chemical must remain in the target area long enough to be effective. Highly persistent products offer increased effectiveness because they remain intact for a long time, but they also increase the risk of environmental contamination. So, a highly persistent chemical, while better for weed control, may also raise environmental concerns.

Application Rate

The rate of application of most chemicals affects their potential for water pollution. As application rates decrease, the potential for loss in surface water and groundwater diminishes. Research shows that this effect is nearly linear (for example, halving the application rate cuts losses in half). Many new pesticides, especially herbicides, are being introduced with much lower application rates than the herbicides they are replacing. And, many of these new herbicides are postemergence chemicals, which can be applied selectively and during periods when excess rainfall is not likely.

Selecting Products With Water Quality in Mind

Chemical properties and rates of application should be considered when selecting chemical products. These considerations hold true for all tillage systems but may be more important with conservation tillage, since many chemicals may be surface applied with little or no incorporation. The properties of solubility and adsorption are usually inversely related; that is, as one value goes up, the other goes down. However, this relationship does not always hold, so farmers who do not know the chemical properties of a product should check with the county Soil Conservation Service or Extension office for information on effectiveness, application recommendations, and management techniques that maximize effectiveness.

Chemicals can be grouped according to the adsorption coefficient, K, into three groups:

- high K values (100+), which are lost primarily with sediment;
- intermediate K values (1–100), which are lost primarily in surface runoff water; and
- extremely low K values (0–1), which are lost primarily in subsurface drainage water.

Most widely used pesticides fall into the intermediate K group. High-K products like glysophate (Roundup, for example) and phosphorus fertilizers are lost through the movement of sediment and can be controlled by limiting soil erosion. An example of a low-K-value chemical is nitrate; it is highly soluble and is not attracted to soil and thus readily moves through the soil and into the shallow groundwater.

Management Considerations

Incorporation of chemicals into the soils is minimized in many conservation tillage systems because of concern about retaining residue on the surface. As a result, many farmers rely on surface-applied chemicals. With high residue covers, chemicals are directly applied to crop residues where they may evaporate or where they may be lost in surface runoff water during a storm event. In conservation tillage systems, surface-applied chemicals with moderate K values are more likely to be lost in surface runoff than incorporated chemicals. But, conservation tillage systems also minimize surface runoff because of better infiltration. These counteracting trends make it difficult to predict the effect of conservation tillage on surface water quality. It can be said, however, that conservation tillage alone will not always solve surface water quality problems. Proper selection and management of chemicals to reduce potential water pollution is also needed.

As mentioned, with medium-K-value chemicals comes the additional potential of rapid leaching to the shallow groundwater through macropores. In high-residue tillage systems, especially no-till, the soil develops many macropores created by earthworms, root channels, and other natural processes. Because of these macropores, chemicals dissolved in surface water move more quickly to the shallow groundwater, with little or no flow through the soil mass. This "short circuiting" of water may generally bypass the filtering action of the soil and transfer contaminants already in the surface water through the soil to shallow groundwater. On the positive side, the water percolating through the macropores also bypasses nitrates and other soluble compounds in the soil so they are not swept out of the root zone. Movement via macropores is more evident after extended periods of dry weather when soils exhibit large cracks. When groundwaters and soils are deep, the macropores generally do not extend to the groundwater and percolating waters are subjected to more filtering action.

The advantage of conservation tillage with high-K-value chemicals is well documented. By controlling erosion, conservation tillage leaves these chemicals in the soil to perform their intended function.

The effect of conservation tillage on low-K-value chemicals is not so consistently straightforward. Conservation tillage, by increasing infiltration and lowering evapotranspiration rates, should increase the potential for soluble, poorly adsorbed chemicals to leach. Recent research shows that nitrate in conservation tillage systems does not always exhibit increased leaching to groundwater. The fact that soils are not tilled or are less aggressively tilled causes less nitrogen to be released from mineralized organic matter in the soil. The combined effect of these two opposing trends is difficult to predict, but recent work in Iowa indicates that conservation tillage systems are more likely to result in lower nitrate losses from leaching than are conventional tillage systems.

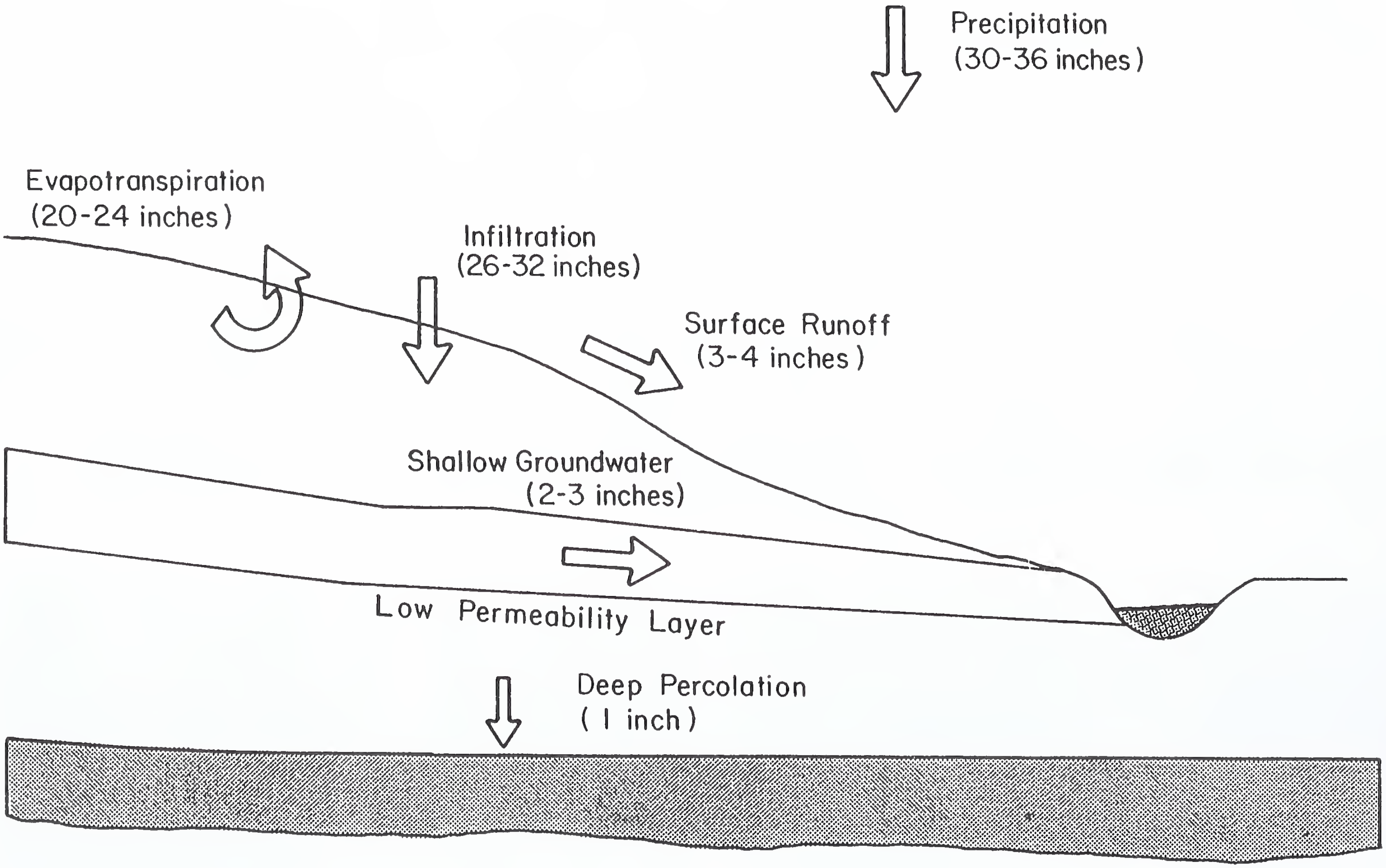

Figure 9. Typical hydrologic cycle in a field in the North Central Region

14 Soil Compaction

A.J. Jones, J.C. Siemens, W.B. Voorhees, R..D. Grisso, and T.E. Schumacher

Soil compaction can be detrimental to soil health, crop productivity, and environmental quality. Across the North Central Region, concern about compaction has been growing because of the increased size and weight of field equipment, the need to perform field operations when soils are wet in order to deal with the larger number of acres per farm, and the diminishing margin of crop profitability. Surveys of the western Corn Belt show that up to 40 percent of fields have some compaction within the surface 15 inches of soil.

Characteristics of Compaction

A silt loam soil having good tilth consists of about 50 percent pore space and 50 percent sand, silt, clay, and organic matter. Pore space is filled with a combination of air, water, and dissolved nutrients. Organic matter helps bind the soil particles together by physical and chemical forces to form aggregates. These soil aggregates impart essential capacity to hold water and supply nutrients and make it easier for plant roots to reach and extract these vital components.

Together soil texture and aggregation largely influence soil bulk density and soil strength—the two properties that characterize compaction. Thus, soils vary markedly in their susceptibility to compaction. As soil consolidation occurs, bulk density increases. A typical uncompacted mineral soil has a bulk density of 1.3 g/cm^3 or less, while a soil high in organic matter, such as a peat, may have a density of less than 1.0 g/cm^3. Most soils if compacted to densities greater than 1.6 g/cm^3 can be expected to limit root growth and possibly crop yields. Bulk densities of 1.40–1.45 g/cm^3 are very common for North Central Region soils and densities of 1.5 g/cm^3 are frequently found in farm fields.

Soil strength is the ability to resist deformation and displacement by an applied force. This characteristic is very dependent on soil conditions, especially water content, and so a numerical value that ties strength directly to compaction is not as meaningful as a numerical value for bulk density. Soil strength measurements taken in the row at a depth of 4–6 inches after 10 years of continuous tillage in Nebraska averaged 307, 331, and 213 lb/in^2 for no-till, disk, and plow, respectively. Soil-water status at the time of sampling was at a near field capacity.

The Compaction Process

The compaction process forces soil particles together. In most farming operations, forces come from wheel and animal traffic and tillage implements. Compaction is minimal if traffic and tillage occur when soils are dry or frozen. Compaction can be severe and last many years if tillage and traffic occur when soils are wet, especially if the traffic consists of heavy wheels.

Wheel traffic and grazing animals exert pressure on the soil surface, causing the greatest compaction near the surface and diminishing with depth. Nevertheless, compaction due to wheel traffic has been measured as deep as 3 ft. Compaction from tillage implements is greatest where the tools shear wet soil. The depth can vary from 2 to 3 inches for a field cultivator to 20 inches for a subsoiler. On different soil types, similar field operations or grazing can result in substantially different compaction levels. Sandy soils can bear up to 3–4 times the applied pressure before compaction occurs, compared with a clay soil, as indicated in the following tabulation:

Soil texture	**Bearing capacity at 80 percent water-holding capacity (lb/inch)**
Sand	27–32
Sandy loam	18–24
Clay loam	10–17
Clay	6–8

Effects on Soil Properties

The physical properties of soil are those most affected by compaction. Compaction increases bulk density, and this increase causes a proportional decrease in the pore space that air and water occupy. Large macropores, which exchange air and water between the soil and the atmosphere and allow water to drain, are reduced in number and size.

Compaction slows water infiltration and drainage due to the reduction in soil pore size and volume. Secondary effects of these changes can include increased runoff and erosion on sloping land and ponding of water for extended periods on level land and low areas. Smaller diameter pores increase the soil-water content at field capacity, thus, decreasing the aeration that crops need for good plant-root respiration and microbial activity.

In a typical uncompacted soil with good aeration, microbes convert organic nitrogen to nitrate-nitrogen that plants can use. In compacted, wet soil, microbial activity can be anaerobic (without oxygen). In such cases denitrification occurs in which nitrate-nitrogen converts to nitrogen gas that escapes into the atmosphere and is not available for the crop. Phosphorus and potassium also appear to be less available to a crop in compacted soil because of reduced aeration. Little information is available on compaction and the availability of secondary micronutrients.

Soil strength increases with compaction. For any given load, those soils with good aggregation are not as likely to increase in soil strength as much as those with poor aggregation. Soils that have a naturally high soil strength are not as likely to compact as soils that have a naturally low soil strength.

Effects on Crop Growth

A moderate amount of localized compaction around the seed is needed for uniform germination. Seeds are planted firmly to ensure adequate uptake of water for germination. However, plant emergence can be delayed or prevented if soil compaction is so severe from planter press wheels that shoots cannot penetrate through the soil surface before the nutrient reserves of the seed dissipate. Large-diameter seedlings with cotyledons, such as soybeans, have greater difficulty emerging than grain crops do. Emergence problems can reduce plant populations, cause uneven stands, and increase susceptibility to disease and insect damage.

Crops growing in compacted areas typically are shorter with less total above-ground mass and have stunted, deformed roots and shallower root systems. An inadequate root system may cause moisture and nutrient stress later in the growing season, depending on the availability of water and nutrients. In wet conditions a compacted soil can cause slow crop growth and can cause leaves to yellow due to nitrogen deficiencies associated with poor root aeration. The greatest concern under wet conditions is the impact that a compacted soil has on drainage. Reduced drainage can cause the soil to remain saturated or to pond for long periods of time. Most crop roots cannot survive in a saturated soil.

Compaction can influence the occurrence of pests and efforts to control them. Based on a few studies, Phytophthora root rot seems to be more prevalent in soybeans growing in compacted soil than in uncompacted soil. The pesticide trifluralin has been found to reduce secondary corn root development by as much as 60 percent at high soil bulk density.

Yield response to compaction depends upon the depth and degree of compaction, type of crop, soil type, and climatic conditions during the growing season. The majority of information obtained from experiments and farmers indicates that yields can be reduced 10 percent or more. Table 11 compares yields from crops produced on compacted and uncompacted soils. Greater yield reductions can be expected in areas where wheel traffic is excessive, such as at the field entrance and turnrows. In years with adequate and timely rainfall or irrigation, compaction may not reduce yields.

Wheel Traffic

Compaction created by wheel traffic may be shallow, which involves soil above the tillage zone, or deep, which develops below the tillage zone. The extent of shallow compaction depends on the load each tire supports and the size of the tire footprint. On a hard surface the pressure on the soil about equals the tire inflation pressure. If the load increases, say from ballast or fertilizer tanks, the tires flatten somewhat to create a larger footprint. Pressure in the soil starts to increase over the inflation pressure of the tire when (1) the tire sidewalls apply pressure directly to the soil, (2) the soil is soft and the tire does not deflect, and (3) the pressure near the tire lugs is much higher than the inflation pressure.

Deep compaction is primarily associated with axle load. A 140-horsepower, two-wheel-drive tractor may weigh 17,000 lb and carry 13,000 lb on the rear axle, while a large four-wheel-drive tractor may approach 40,000 lb with 20,000 lb on each axle. Combines and grain carts are also commonly associated with deep compaction. A large combine can have a front-axle load of 17 tons or more while single-axle grain carts can have axle loads of 40 tons per axle.

Tire type and configuration are also factors in compaction. Radial tires have a larger—that is, a longer—footprint than bias ply tires and cause less shallow compaction. Radials also supply better traction than bias ply tires, meaning that less ballast is needed to operate equipment efficiently. Soil pressure can be reduced by using duals, triples, steel or rubber “tracks,” or flotation tires. These different tire configurations all offer wider footprints that disperse equipment weight over more surface area. Two cautions are in order: (1) the weight of extra tires (duals, triples) and ballast increase axle load, and (2) use of larger tires or more tires subjects a larger portion of the field area to compaction.

Livestock Traffic

Livestock exert pressure on the soil and degrade soil structure by the churning action of their hooves. The applied pressure and “axle” load equivalent of a 1,000-lb cow is considerable. Stocking rate, availability and location of feed and residue, animal species, and position of water all influence animal traffic patterns, grazing intensity, and potential compaction.

Livestock that graze dry soil have little effect on compaction because dry soil is not easily compressed and usually has high strength. However, when soils are wet, livestock can cause considerable damage to depths of 12 inches or greater. Increased bulk density and increased soil strength near the surface from grazing result in a loss of large soil pores responsible for drainage and aeration. Penetration of hooves also remolds the surface soil, reduces infiltration, lowers water-holding capacity, and, as mentioned, destroys soil structure.

During winter grazing, livestock can tear the roots and growing tips of winter wheat and hay, leaving them susceptible to disease and insect infestations and causing severe enough damage to prevent spring regrowth.

In ridge-till fields, livestock tend to walk in the furrows and graze on the rows. As grazing time or intensity increases, the livestock increasingly trample residue in the furrows, destroy potential feed, and wind up grazing and compacting more of the field than if they were grazing a no-till or mulch-till field, which is relatively flat.

Grazed fields can have a high soil strength and bulk density, especially no-till fields because they are not tilled after grazing. High soil strength can reduce the amount and depth of crop rooting, but cracks, fissures, old root channels, and wormholes provide low-resistance paths for new root growth through compacted zones. Without grazing, no-till and mulch-till systems tend to have greater soil porosity and lower bulk density throughout the growing season, compared to plowed soils, which consolidate rapidly after tillage.

Compaction and Residue Management Systems

In management systems that keep residue on or near the soil surface, soils are often wetter after a rain or after irrigation. As mentioned, wet soils have less strength and are more prone to compaction, and soils near field capacity are most susceptible to compaction. Reduced-till and no-till systems with markedly improved soil structure can create an environment that resists compaction. For example, wheel traffic on a highly structured no-till soil at field capacity will cause less compaction than wheel traffic on a poorly structured plowed soil at field capacity. Nevertheless, in no-till systems efforts should be made to minimize compaction because in these systems tillage typically is not used to break up consolidated soil.

No-till promotes an increase in organic matter, especially near the soil surface. After several years of intensive tillage and declining organic matter, a no-till system can stabilize or increase organic matter content, improve soil structure and aggregation, increase water-holding capacity and infiltration, and enhance resistance to future compaction.

Strategies To Minimize and Eliminate Compaction

Nature has many processes that alleviate soil compaction, among them, wetting and drying and freezing and thawing. The machine-intensive farming of the past 20–30 years has made it difficult for natural processes to have a positive effect on the soil environment. Listed below are strategies that can reduce the risk of soil compaction, are beneficial to the long-term sustainability of crop productivity, may alleviate soil compaction that has already developed, and help meet the erosion goals of conservation plans.

Stay off wet soils. Perform field operations in the driest fields first, thus allowing more drying time for fields that tend to remain wet. Reducing axle load and increasing tire size help reduce deep compaction on susceptible fields.

Reduce tillage. Management systems with a reduced number of tillage operations leave greater amounts of residue on the soil surface. Surface residue helps prevent surface sealing by intercepting raindrops. Surface sealing is a form of compaction that increases runoff and forces emerging seedlings to expend substantial energy to break through the crust. Weak, disease-prone seedlings can result.

Add organic matter to the soil. Crop residue, animal manure, sludge, and green-manure crops all provide organic matter that can promote good soil structure and decrease bulk density. The soil resulting from these additions will be more resistant to compaction by tillage or wheel traffic.

Rotate crops. Crop rotations—including perennials such as alfalfa, clover, and grass—result in less compact soils. This effect stems from (1) absence of tillage operations after seeding, (2) field operations that are typically limited to hay harvesting when the soil is dry, and (3) deeper rooting that keeps soil more porous and removes large amounts of water, which promote soil drying and cracking.

Alter the depth of tillage. If tillage is used, it is important to till deeper in a dry year to break up the “tillage pan.” In subsequent years, vary the tillage depth to minimize development of a compacted zone. With shallow tillage, compaction occurs just below the depth of tillage. Shallow tillage leaves more of the crop residue on the soil surface, a condition that promotes better structure in the surface soil.

Control wheel traffic. Compaction can be localized if all tires are restricted to the same tracks or row middles. Tilling, planting, spraying, and harvesting equipment that have the same wheel spacing make controlling traffic relatively possible. Wheel traffic is easiest to control in ridge-tillage and no-tillage systems.

Plan harvest strategies. Combines, grain carts, and grain trucks are among the heaviest equipment used on a field. Especially under wet field conditions, one might avoid filling the combine to capacity and can keep grain carts and trucks off the field by emptying the combine at the end of the field. If using carts and trucks to unload in the field, keep cart and truck tires in the combine tractor tracks of the previous pass. When transporting equipment from the field, create and use only one path to the extent possible.

Use deep tillage when compaction limits crop yields. Visual inspection of crop roots helps determine the depth and extent of compaction. The subsoil or chisel plow are the most common tools used to break compaction. If deep tillage is performed, some of the strategies given above should be considered to maximize the effectiveness and longevity of the operation.

Manage livestock grazing. Livestock should be allowed to graze on cropland when the soil is dry or frozen. Rotational grazing should be used and stocking rates adjusted depending on soil and forage conditions. As mentioned previously, considerable trampling of residue can be expected. One should remember to subtract the residue eaten by animals when estimating the residue cover required to prevent erosion.

Table 11. Crop production in compacted and uncompacted soils in North Central states

Crop	Soil type	Compacted	Uncompacted	Percent change	Year
Sugarbeets					
Nebraska (kg sucrose/ha)	Very fine sandy loam	5,500	8,530	−35	1979
North Dakota (tons sucrose/acre)	Silty clay loam	1.53	1.23	+24	1979
North Dakota (tons sucrose/acre)	Silty clay loam	1.51	1.60	−6	1980
North Dakota (tons sucrose/acre)	Silty clay loam	1.89	1.78	+6	1983
Corn (bu/acre)					
Wisconsin	Silty loam	129	163	−21	1986
Illinois	Silty clay loam	145	150	−3	1986–91
Kansas	Silty clay loam	111	124	−10	1963
Kansas	Silty loam	104	106	−2	1963
South Dakota	Loam/fine sandy loam	111	123	−10	1991
Potatoes					
North Dakota (cwt/acre)	Silty clay loam	128	136	−6	1983
Soybeans					
Illinois (bu/acre)	Silty clay loam	37	38	−3	1986–91
Minnesota (kg/ha)	Clay loam	29	30	−3	1982–86

15 Effects of Crop Residue on Infiltration, Evaporation, and Water-Use Efficiency

D.C. Reicosky and W.D. Kemper

The amount of water available for crop use is determined primarily by rainfall and evaporation. Studies show that residue-covered surfaces reduce soil-water evaporation and increase infiltration. Additional water stored in the root zone usually translates into higher crop yields and increased water-use efficiency. The relative benefits of residue in controlling wind and water erosion and in conserving water increase as one moves westward through the North Central Region into the drier regions.

Evaporation

Surface crop residues shade the soil and reduce the amount of the sun's energy absorbed, thereby keeping the soil cooler during the day and reducing evaporation. Residues also reduce air velocity at the soil surface, slowing the rate that the wind blows away water vapor. Residue cover offers the greatest reduction in evaporation when the soil is moist and is not yet shaded by the crop. For example, during the summer fallow period in Nebraska, the water stored in soil under surface straw mulch is about twice as great as it is in plots without residue cover.

A study done in Ohio in the summers of 1962–64 revealed available water in the root zone as follows: 1.68 inches in plowed bare soil; 1.72 inches in no-till bare soil; 2.10 inches in no-till soil with 40 percent cover; and 2.32 inches in no-till soil with 80 percent cover. Root-zone soil water for corn during the peak water-use period averaged more than 0.79 of an inch greater in no-tillage plots than in plots tilled with a moldboard plow.

In Minnesota during the growing season for continuous corn, water content in no-tillage fields average 110 percent of that in fall-plowed fields. In western Iowa, with spring soil-water levels at below-normal levels, conservation tillage increased yields over those from conventional tillage, primarily because of the greater soil-water recharge. The additional water accumulated in no-tillage systems delays the onset of crop wilting, thereby extending the period of crop growth.

The difference in cumulative evaporation between bare soil and residue-covered soil is related to the frequency and amount of rainfall. For small, infrequent rainfall events, the two soil surfaces show little difference in cumulative evaporation. But with larger, more frequent rains, less evaporation occurs from soil protected by crop residue than from bare soil. In dry years and dry areas the economic impact of even a small water savings can be substantial. In a study in Ohio, runoff in a no-tillage field was 0.67 inches in a year, compared with 1.46 inches in a conventional-tillage field. Downward release of water from the root zone increased from 2.09 inches on the conventionally tilled treatment to 4.84 inches on the no-tillage treatment, a finding indicating that evapotranspiration from the no-till soil was less. In the more humid areas of the North Central Region, conservation tillage, including no-till, produces higher yields in areas with better-drained soils.

Increased water passing through the root zone may move more nitrate below the active root zone. Combinations of summer fallow systems and reduced tillage can enhance water conservation during the fallow period and increase nitrate losses. Consequently, in no-till systems it is even more important to synchronize and match nitrogen application to crop needs so crops absorb most of the nitrate before the fallow period.

In stubble-covered wheat fields, evaporation ranges from 60–75 percent of that occurring from bare soils. Evaporation depends on water rising to the surface by capillary action as the soil dries. Shallow incorporation of residue reduces the continuity of the capillary pores of surface soil and can somewhat reduce evaporation. Mulch tillage, which incorporates some crop residues near the surface, reduces cumulative evaporation compared to evaporation from plots where all residues were removed at harvest or were buried deeply by plowing. Leaving residues on the surface generally reduces evaporation more than shallow incorporation.

Infiltration

Infiltration is the process of water entering the soil. Many factors that affect infiltration are interrelated and are influenced by soil and water management. For example, surface crop residue dissipates the beating action of raindrops on the surface, and this in turn reduces surface sealing, increases infiltration, and decreases the amount of potential runoff.

Residue is one of the most effective means of controlling infiltration and soil detachment. Table 12 shows how the amount of residue affected infiltration amounts in a study of the effects of applied mulch. The effects of the residue were twofold. First, surface residue intercepted raindrops and dissipated their energy and associated soil-sealing capability. Second, even low residue rates reduced the velocity and sediment-carrying capacity of runoff water. These data point out the benefits of leaving more crop residue on the surface to control erosion in high-intensity storms of short or long duration.

Simulated rainfall studies in Ohio also show that infiltration increases with surface residue (table 13). While infiltration was greater on a newly plowed field than on a bare no-till field (where residue was removed for experimental purposes), the residue in the no-till field enabled faster water infiltration; the plowed soil soon sealed over from beating raindrops. As little as 450 lb/acre of residue has been shown to significantly increase infiltration and reduce runoff. As a larger portion of precipitation infiltrates, it may move more nitrates into the groundwater. The significant benefits and detriments of such displacement are discussed in chapter 13.

While no-till cropping systems that maintain residues on the surface generally will reduce runoff, there are exceptions, such as in instances where (1) the preceding crop left behind little residue, (2) the period of no-till was too short for benefits to develop, (3) the climate was too dry even for no-till management to sustain macropore makers such as earthworms, or (4) subsurface layers such as claypans are the primary factors restricting infiltration. Residues reduce soil movement more than they reduce water movement. Mulch-till treatments, which leave some residues on the surface while breaking surface crusts and roughening the surface, generally decrease runoff more than treatments that bury residue do.

In northern climates, keeping the surface protected from the beating action of raindrops in the late winter and the spring is essential to maintaining good infiltration and controlling erosion in many soils. Here, freezing and thawing of the surface soil can affect erosion by reducing the soil's bulk density, hydraulic conductivity, shear strength, and aggregate stability. Repeated freezing and thawing disintegrate aggregates and make soil particles susceptible to detachment and movement. When rains come or snow melts while the underlying soil is frozen and cannot absorb water, practically all of the water runs off, often taking a large part of the disintegrated soil with it. Gentle wetting by dews or drizzles, attendant mineral solubilization, and increased cohesion and cementation during the drying process can bond particles back into aggregates. However, if the soil surface has been beaten into a dense layer, these same processes can bond the soil particles into still stronger crusts that inhibit seedling emergence and keep infiltration rates low.

Crop residue management can indirectly alter the depths to which soil freezes. Snow trapped by standing residue insulates the soil and decreases the depth of freezing. In a study conducted in central Minnesota, standing corn stubble that had trapped the snow kept the soil from freezing below a depth of 20 inches; in a treatment where wheat stubble was buried, the soil froze to a depth of 43 inches. Many years over wide areas of the northern plains, thick, insulating snow that is stabilized by standing wheat stubble allows heat from deep within the soil to thaw the frozen soil. Then, the soil absorbs most of the melted snow, adding to the water conserved.

Plant Characteristics That Affect Infiltration

For several weeks after planting the soil is essentially unprotected. As leaf area develops, the plant canopy protects the soil surface from the impact of raindrop. Long-term erosion studies show that the canopy cover of agronomic crops is influential in protecting the soil and maintaining infiltration during the latter part of the growing season. Residues from previous crops are essential for providing the protection needed during those early months before the canopy forms.

Cover crops used before or after the agronomic crop extend live cover during the off season, at least until severe temperatures are encountered. Even when the cover crops are killed by freezing, their residues augment those from the previous crop. Because cover crops can deplete stored soil water and reduce cash crop yields, the farmer needs to monitor the soil water in the spring and kill the cover crop before it uses water that the cash crop will need later.

Crop roots leave channels in the soil when they decay, and these channels are large enough to allow water to infiltrate if it begins to pond on the surface. Tilling disrupts these channels. Fescue roots loosen the soil and have been shown to increase hydraulic conductivity by an average of 40 percent over soybean roots and 80 percent over bare soil. The higher conductivity has been attributed to root channels from previous years, compared with bare soil with no root channels. Increasing the root density contributes to increasing soil organic matter content, which can also boost infiltration rates and water-holding capacity.

Water-Holding Capacity

The capacity of soil to hold water enables the crop to function and grow. When the available water supply gets low, crop growth slows. When the available water is gone, plants stop producing and begin to die unless precipitation puts available water back into the soil. In most of the North Central Region transpiration is low during the cold months, precipitation exceeds evaporation, and the available water-holding capacities of the soils are filled.

In the eastern portions of the region precipitation minus evaporation often exceeds the available water-holding capacity from fall to spring, and excess water percolates past the root zone to recharge the underlying aquifer. In the drier western portions root zone refill is not always complete. Farther west in the Great Plains regions, the depth of wetting seldom exceeds the depth where roots can reach water, unless summer fallow stops transpiration and allows precipitation to accumulate over a longer period.

The high productive capacity of the North Central Region (compared with the Southeast Region and the Appalachia and Northeast Region, which receive as much or more rainfall) is due partly to the higher available water-holding capacity of the soils. For instance, the available water-holding capacity in most North Central soils ranges from 0.1 to 0.2 inch of water/inch of soil depth; most soils of the Southeast Region have capacities in the range of 0.06–0.15 inch of water/inch of soil.

The total water available to the crop is also affected by the rooting depth. Depth of rooting is generally greater in most of the North Central Region than in the Southeast Region because the soils are younger and have fewer clay pans, fragipans, and other layers that restrict root growth and water flow. Most North Central soils were deposited by glacial action within the last 15,000 years. If one travels a line from Bloomington, IL, south to St. Louis, young soils (where corn production potentials average about 170 bu/acre) give way to older soils (where shallower rooting causes more frequent drought stress and production potentials average about 120 bu/acre).

Higher production rates mean more crop residues are left in the field, which helps soil increase organic matter. Recent evaluations show that a 1-percent increase in organic matter in the top 6 inches of soil increases the water-holding capacity of that layer by about 0.3 inch of water (Hudson 1994). Figure 10 illustrates increases in the residual organic matter of topsoils under long-term no-tillage in Ohio. Organic matter in the top inch of soil is particularly important because it stabilizes the surface against the disruptive forces of wetting, freezing, thawing, and pounding of raindrops (Mielke et al. 1986).

In figure 10, the available water-holding capacity in the top 6 inches of the no-till soil is almost 1/2 inch of water greater than it is in conventionally plowed soil. Part of this difference is due to a reduction in the available water-holding capacity of the conventionally tilled soil associated with declining residual organic matter (see chapter 17 for more detail).

In addition to the annual winter fill-up, the available water-holding capacity of topsoil is also often filled to the rooting depth at least once during the early part of the growing season. Increments in water-holding capacity associated with increased organic matter content can provide the water needed to keep a crop growing 1–2 days longer when rains are delayed.

An even greater increase in total available water-holding capacity is taking place as a result of increased rooting depths under no-till management in at least some portions of the North Central Region. Roots of soybean plants have been observed to penetrate deeper under no-till where earthworm populations have increased. Apparently, crop roots grow better down through the earthworm burrows.

For over 50 years soil scientists have recognized that crop roots grow more deeply into subsoils that have a large portion of their exchange capacity filled with calcium ions than into acid soils, which have a large portion filled with hydrogen and aluminum ions. Farmers and scientists have spent hundreds of dollars per acre to incorporate calcium-rich lime to depths of 2 or 3 feet in acid subsoils, with the result that roots have grown deeper and yields have increased due to reduced incidence of drought stress. However, the costs of incorporation have been so great the practice has not been economically feasible on a field scale.

Early assessments of no-till soils found that calcium from surface-applied lime quickly mobilized and leached out, leaving the soil surface more acid than it was when tilled. It was soon recommended that lime be applied more often with no-till than with conventional tillage. The long-term effects of this mobilization of calcium became apparent in the Coshocton, OH, plots, where after 16 years of no-till and frequent surface liming, calcium moved about 2.4 ft deep into the soil (see fig. 15 in chapter 17). This trend to more downward migration of calcium has been noted in other no-till fields. It can be optimized by leaving the manure, the crop residues, the lime, and the ammonium forms of nitrogen, including urea, together on the surface. Increased rooting depths, fewer drought-stress days, and improved yields generally accompany calcium migration into acid subsoils and concurrent displacement of aluminum and hydrogen (Sumner 1995).

No-till and to some extent other forms of reduced tillage are slowing or reversing the degradation of soils that has resulted from centuries of tillage. Judicious use of lime or low-cost industrial wastes containing calcium, coupled with no-till management, can increase rooting depths and available water-holding capacities of soils. These are slow processes that are not often detected in short-term trials, but they are contributing to the long-term improvement of water-use efficiency and productivity observed in no-till plots and fields.

Water-Use Efficiency

Water-use efficiency is frequently a concern in the North Central Region, even in the relatively humid eastern portion. It is usually defined as units of crop produced per unit of water used. In the field, the total water used consists of the sum of soil evaporation and plant transpiration. Reduced evaporation and increased infiltration can contribute greater quantities of stored soil water up to the limit of the soil profile water-holding capacity. Additional water percolates to the groundwater as drainage. In cases where groundwater recharge is needed this drainage from the root zone has value by making well supplies more dependable and by increasing the base flows of streams. In cases where the water table is already too high, these additions may be detrimental.

Water-use efficiency is strongly affected by environmental factors such as rain and snow (which supply soil water), and air temperature, humidity, solar radiation, and wind (which subtract soil water). Other influencial factors are the plant species and the timing of plant growth in relation to rainfall events and amounts of rain. Plants with deeper root systems and longer growing seasons are able to extract more water. The period when surface crop residue most affects evaporation and infiltration is from harvest until canopy closure the next spring. Following canopy closure, only a small portion of water is lost as soil evaporation. Most is lost by transpiration—evaporation from the leaves.

The amount of water transpired is usually proportional to the total dry matter produced, which determines the amount of residue available to cover the soil surface during the following year. This link between transpiration and dry matter makes management to increase the water available to crops one of the farmer's best investments because it provides short-term and long-term returns.

The effects of crop residue and conservation tillage in modifying the water balance have not been precisely quantified, primarily because of the practical difficulties involved in measuring evapotranspiration and drainage. Estimates made in Kentucky indicated that no-till decreases evaporation and increases subsurface drainage when runoff from no-till and conventional tillage is prevented. Under conventional tillage, soil-water evaporation was 5.9 inches more and plant transpiration was 2.0 inches less. Total evapotranspiration was 3.9 inches greater under conventional till. Percolation to groundwater was more than twice as much in the no-till plots, partially as a result of lower soil evaporation (table 14). These combined effects of residue and tillage demonstrate the magnitude of their impact on the availability of water for transpiration and groundwater recharge.

Keeping crop residues on the surface has the potential to conserve more water in the more humid areas of the region because there is more rainfall. In the more arid portions of the region where lack of water limits plant growth more frequently, conserved water often has more effect on crop production. Cumulative soil-water evaporation as a percentage of evapotranspiration from a corn crop was as much as 56 percent in Ohio (Harold et al. 1959), 46 percent in Iowa (Shaw 1959), and 50 percent in Illinois (Peters and Russell 1959). The amounts of water evaporated from soils in Ohio and Illinois were 10.7 and 6.5 inches, respectively. Such findings underscore the importance of surface residues in lessening significant water loss.

The amount of residue produced per inch of water used by various crops in Kansas is presented in table 15. Crops are generally planted for grain yield, but the amount of residue produced per unit of water transpired is pertinent to water conservation. Corn, sorghum, and millet produce larger amounts of residue per unit of water than soybeans, pinto beans, and sunflowers. Thus, where water limits crop growth and optimized erosion control and economic return are desired, the farmer should give serious consideration to selecting the appropriate crop.

A key to a sustainable food supply is to manage crop residue to protect soil resources and to control the basic hydrologic processes of evaporation, infiltration, and water retention to optimize crop water-use efficiency. Within the North Central Region, the potentials for achieving these objectives vary because of differences in physical characteristics of soils, in chemical, topographic, rainfall, and temperature characteristics, in crops grown, and in tillage systems employed.

Leaving crop residues on the surface generally increases infiltration and decreases evaporation, which make more water available for crop use and groundwater recharge. How much of the water from a specific rainfall becomes available to crops and how much goes to groundwater depends on the amount of rainfall, the capacity of the soil to hold available water, and the extent to which the available water-holding capacity is filled before the rainfall.

Refraining from tillage in combination with crop residues can effect long-term increases in organic matter, improve rooting depth, increase the amount of water available to crops, and reduce days of drought stress. As discussed in chapter 17, these factors account for a substantial portion of the long-term increases in yields of no-till fields compared with plowed fields.

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Table 12. Effects on runoff, infiltration, and soil loss of mulch applied to a Wea silt loam*

Amount of of mulch (tons/acre)	Soil moisture before run, 0–5 inches (% by weight)	Amount of water applied† (inches)	Runoff (inches)	Total infiltration (inches)	Soil content of runoff‡ (%)	Soil loss (tons/acre)
Initial run (60 min)						
0	18.7	2.50	0.49	2.01	2.55	1.73
0.25	19.0	2.50	0.27	2.23	0.90	0.26
0.50	18.3	2.50	0.04	2.46	0.48	0.02
1.0	17.9	2.50	0	2.50	—§	0
2.1	19.5	2.50	0	2.50	—	0
4.0	18.8	2.50	0	2.50	—	0
1st wet run (30 min)						
0	23.8	1.25	0.77	0.48	4.12	3.58
0.25	24.1	1.25	0.65	0.60	1.19	0.88
0.50	23.5	1.25	0.22	1.03	0.71	0.26
1.0	24.5	1.25	0.03	1.22	0.51	0.05
2.0	25.2	1.25	0	1.25	—	0
4.0	24.2	1.25	0	1.25	—	0
2nd wet run (30 min)						
0	—	1.25	0.78	0.47	4.12	3.61
0.25	—	1.25	0.82	0.43	1.20	1.11
0.50	—	1.25	0.65	0.60	0.88	0.59
1.0	—	1.25	0.16	1.09	0.71	0.15
2.0	—	1.25	0	1.25	—	0
4.0	—	1.25	0	1.25	—	0
3rd wet run (30 min)						
0	25.9	1.25	0.79	0.46	3.91	3.50
0.25	26.4	1.25	0.76	0.49	1.10	0.98
0.50	22.4	1.25	0.67	0.58	0.71	0.55
1.0	24.9	1.25	0.11	1.14	0.48	0.10
2.0	25.3	1.25	0.09	1.16	—	0
4.0	24.8	1.25	0	1.25	—	0
All runs						
0	—	6.25	2.83	3.42	3.7	12.42
0.25	—	6.25	2.50	3.75	1.1	3.23
0.50	—	6.25	1.58	4.67	0.8	1.42
1.0	—	6.25	0.30	5.95	0.6	0.30
2.0	—	6.25	0.09	6.16	—	0
4.0	—	6.25	0	6.25	—	0

* Plots were 35 ft × 12 ft, with a 5 percent slope. Values shown are averages of two replications.

† Water was applied at an intensity of 2.5 inches/hr.

‡ Percent by weight of soil in runoff = total soil/total runoff × 100.

§ Data unavailable.

Source: Mannering and Meyer 1963.

Table 13. Effect of tillage and corn residue on infiltration using simulated rainfall on a Wooster silt loam in Ohio*

Treatment	Total infiltration after 1 hr (inches)	
	Initial run	Wet run†
Plowed, bare	0.71	0.41
No-tillage, bare‡	0.48	0.25
No-tillage, 40 percent residue cover	0.92	0.53
No-tillage, 80 percent residue cover	1.73	1.37

* Plots had a 1–2 percent slope.
† Wet run took place 24 hr after initial run.
‡ Residue was removed for research purposes.

Source: Triplett et al. 1968.

Table 14. Estimated average evaporation, transpiration, and subsurface drainage in continuous corn in Kentucky, May–September growing seasons, 1970 and 1971*

Treatment	Evaporation	Transpiration	Total evapotranspiration	Drainage
	inches			
Conventional tillage	7.7	9.5	17.1	1.1
No-tillage	1.8	11.5	13.3	2.4

* Values were averages of the two seasons. Total rain averaged 21.7 inches for the two seasons.

Source: Phillips 1981.

Table 15. Residue produced per unit of water used by crops in Kansas*

Crop	Grain yield (tons/acre)	Residue yield (tons/acre)	Amount of water used per season (inches)	Ton/acre of residue from each inch of water used
Corn	3.37	5.59	22.2	0.252
Sorghum	2.80	4.20	19.1	0.220
Millet	1.08	5.88	19.3	0.305
Pinto beans	0.93	2.10	16.7	0.126
Soybeans	1.32	2.56	21.3	0.120
Sunflowers	1.02	3.98	21.5	0.185

* Measurements are averages of those taken at two locations for 2 years.

Source: Hattendorf et al. 1988.

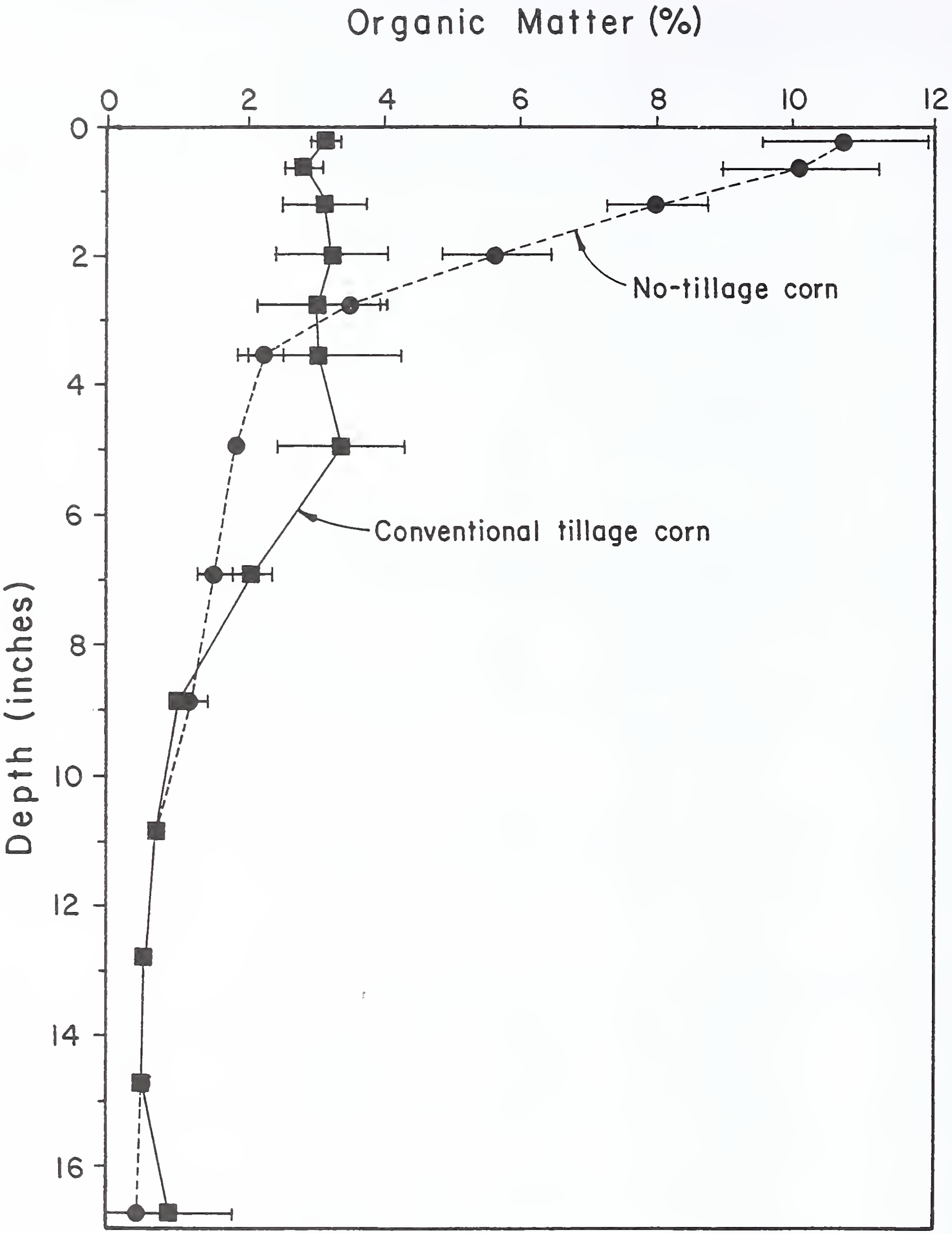

Figure 10. Percentage of organic matter at various depths in no-till corn and conventional tillage corn, Coshocton, OH. Source: Edwards et al. 1988.

16 Interactions of Crop Residue With Soil and Climate

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Tillage and crop residue interact with soil and climate to affect plant growth. This interaction causes changes in the soil moisture of the seedbed, water infiltration, water storage, evaporation, soil temperature, soil strength, and soil density. These variables also interact to affect planter performance, including the degree of seed-soil contact and the depth and uniformity of seed placement. Tillage, residue cover, and soil type create seedbed conditions, which interact with climatic conditions to influence germination, emergence, and early growth. They may affect the rate of phenologic development, stand, and yield of corn.

Seedbed Conditions

The rate of germination depends on the temperature around the seed and the rate the seed absorbs moisture. The rate of emergence also depends on how much soil resistance slows and interferes with the shoots. Inhibitory chemicals that leach out of crop residues can affect seedling development. Reducing the amount of crop residue in the seedrow minimizes this possibility and increases the rate of warming in the seedbed. Large amounts of in-row crop residue at planting can interfere with seed placement, which may reduce the plant population.

Soil Temperature

Whether and how much reductions in soil temperature from in-row crop residue affects crop growth and grain yield depend on the region, the yearly climatic conditions, the crop grown, the previous crop, and the soil. Corn is more sensitive to reduced soil temperature than small grains or soybeans, partly because corn evolved in a warmer environment. Soil temperature also has a pronounced effect on early corn growth because the growing tip remains in the soil or within about 1 inch of the surface for the first 4–6 weeks until about six leaf collars emerge. Delayed growth due to residue-induced reductions in soil temperature is more likely where corn follows corn than where corn follows soybeans or alfalfa because there is less crop residue cover following the latter two crops.

The early growth, stand, and yield of soybeans are less sensitive to in-row crop-residue-induced reductions in soil temperature than corn is because the growing tips of soybeans emerge more rapidly. Soybeans take up phosphorus and potassium later in their growth period than corn does, so the effects of early-season soil temperatures on nutrient uptake are less important.

Areas with less than about 2,800 °F annual growing degree days for corn and soils having poor internal drainage increase the probability that decreased soil temperature because of crop residue will reduce early corn growth and yield. These conditions increase the possibility of decreased corn yield in short growing seasons that are not affected by drought. In northern Indiana reduced spring soil temperature slowed corn grown under residue cover but did not slow corn growth 200 miles away in southern Indiana, which has a longer growing season (Griffith et al. 1992).

In the northern and central parts of the North Central Region where growing seasons are short, the slower rate of corn growth from low spring soil temperatures can delay maturity and increase grain moisture at harvest. Yield may decrease if growth terminates before grain filling is complete. Studies of corn in southwestern Wisconsin conducted under conditions of marginal growing degree days and little drought stress showed increased grain moisture at harvest and decreased yield with more than 30 percent in-row residue. Research in Minnesota and Wisconsin indicates that the additional air growing degree days required for corn to reach the six-leaf stage with a 70-percent cover of corn residue are about equal to the difference in air growing degree days between a normal 105-day hybrid and a 95-day hybrid in southern Minnesota. Thus, a 105-day hybrid without residue cover would mature at about the same time in southern Minnesota as a 95-day hybrid with 70-percent corn residue cover.

Seed Placement

The presence of corn residue in the row at planting can lead to nonuniform depth of seed placement, which contributes to reduced emergence rates and grain yields. On a silt loam soil in southwestern Wisconsin, use of clearing discs on continuous corn to remove residue from the row decreased the variation in planting depth and increased the planting depth in most years, compared to results obtained from fluted coulters, where residue was cut but not removed.

Corn planted into soybean residue is less likely to sustain stand loss and experience delayed growth than is corn following corn. When corn follows soybeans, seed placement and seed-soil contact improve because of less residue at planting. There are smaller amounts of residue following soybeans than corn and more rapid decomposition of soybean residue. There is also less likelihood of inhibitory chemicals leaching from soybean residue than from corn residue.

Note: See chapters 12, 15, and 17 for additional information related to this chapter.

Soil-Water Conditions

Although soil temperature is usually the main factor controlling seed germination, soil water also plays a role. Crop residue management improves soil-water status in sandy soils and other well-drained soils that have a naturally low water-retention capacity.

Crop residue conserves water for crop use by increasing infiltration and decreasing evaporation. However, when rainfall does not occur for long periods, the amount of water that crop residues conserve will be small unless there are large amounts of residue or the water can be moved deeply into the soil (Van Doren and Allmaras 1978). Tillage generally increases the evaporation rate from the tilled zone. Because adequate soil water must be present for germination, planting into untilled soil generally improves the probability of sufficient moisture.

Numerous studies in the North Central Region indicate that transpiration deficit or water stress reduce corn grain yield. Results from a broad range of studies show that water is the most common factor determining potential corn grain yields. Other factors, such as fertility, weeds, and pests, also limit yields.

Field studies in the Great Plains show that significant amounts of water can be stored by using crop residue mulches. The mulches decrease evaporation by reducing the amount of energy reaching the soil surface and by reducing water movement. Effective weed control is an essential part of making such water conservation efforts successful, as well as the tillage method and the amount of residue present by the previous crop.

In-Row Residue

Because crop residues are primarily responsible for slow soil warming in no-till systems, clearing residues from the seedrows into the interrows should result in corn growth comparable to that in tilled systems. Such clearing allows solar radiation to reach the soil surface, which increases soil temperature, thus speeding seed germination and seedling growth. To maintain the erosion-control benefits of crop residues the amount displaced from the row should be reduced only as much as required to increase soil temperature to the desired level in the row area.

Clearing residue from a narrow band over the seedrow produces thermal conditions similar to those of conventional tillage. In a study in Wisconsin differences in average daily soil temperatures obtained in May and June were determined for three management methods: (1) moldboard plow, (2) no-tillage, and (3) no-tillage with residue removed from a 12-inch-wide band centered over the seedrow. The average daily temperature at a depth of 2 inches was 6.7 °F warmer with moldboard plowing than with no-till with residue remaining in the row. Clearing residue from a 12-inch band in no-till reduced the temperature difference to 1.1 °F. At the 4-inch depth, the average daily soil temperature was 0.8 °F lower for no-till with residue removed over the row than that measured for the moldboard plow.

Iowa researchers examined the impact of the width of residue-free bands on corn growth and yield (Kaspar et al. 1990). At the start of each year all residues were removed from the plots. Some plots were plowed and others were managed with no-till. Corn was planted, and corn and soybean residues were manually distributed on the plots, leaving residue-free bands of 0, 3, 6, and 12 inches wide around the rows. The rows were 30 inches apart, and a residue-free plot was included for comparison.

Daily soil temperatures were averaged over the 20-day period from May 25 to June 13. Temperatures were taken at a depth of 2 inches in the seedrow and compared with those of bare soil. Corn residues reduced maximum soil temperature by 12.2 °F in 1983 and 8.3 °F in 1984; soybean residues reduced soil temperature by 9.7 °F in 1983 and 7.6 °F in 1984. Temperatures taken in a 6-inch residue-free band were less than those taken in bare soil but much greater than those of residue-covered soil. Other researchers observed that under a 20-inch-wide band covered with residue, mean soil temperature at the 2-inch depth decreased 3.2 °F.

The 6-inch-wide residue-free band gave yields within 3 percent of those obtained from bare soil, while leaving 79 percent of the soil surface covered. Savings from fuel, machinery, and labor may offset the losses from a 3 percent yield reduction. Furthermore, water conservation from surface residue may increase corn yield under conditions where insufficient water limits yield. So, clearing residue from the seedrow can be an effective way to improve corn yields, if cool early-season temperatures and abundant residues reduce yields, if soils are not susceptible to crusting, and if soil moisture at planting is adequate.

Managing Residue in Less-Than-Optimal Conditions

Cold Soils

As discussed previously, crop residues reduce seed-zone temperatures during the early growing season of corn and other spring-planted crops. However, surface residues also affect overwinter soil temperatures and depth of soil freezing. A study conducted in western Minnesota from late fall to early spring showed that reduced tillage with standing stubble caused a greater accumulation of snow. This resulted in reduced freezing, earlier disappearance of frost, and warmer soil temperatures during the winter and early spring period. More intense tillage operations that left no standing residue caused less snow accumulation, deeper freezing, and colder soils which retained frost later into the spring.

In winters with little snowfall, the effects of residue were not apparent, indicating that snow accumulation is the major factor affecting winter soil temperature and frost penetration, not residue alone. In Minnesota a no-tillage treatment after corn achieved a frost-free status 10–30 days before other conservation tillage systems and supported slightly higher soil temperatures until just before spring corn planting.

One benefit of warmer winter soil temperatures from accumulated snow is the winter survival of perennial crops and fall-seeded crops. Researchers at Fargo, ND, demonstrated nearly a 100-percent winter survival rate of winter wheat seeded into 7-inch standing stubble over a 4-year period. In adjacent tilled plots, the survival rate was less than 50 percent in 2 of the 4 years.

Wet Soils

Removal of residue from the row in areas where spring soil temperatures are below optimal for seed germination frequently increases the grain yield of continuous corn on poorly drained soils in the northern part of the North Central Region. Research here shows that no-till often produces lower grain yields in continuous corn than moldboard plowing does, but equal or near-equal yields of corn following soybeans. On poorly drained soils, planting on elevated ridges and removing residue from the row area produces better yields of continuous corn than no-till where corn residue remains in the row. Yields of corn grown with ridge tillage equaled yields of continuous corn grown with moldboard plowing in studies on a poorly drained Hoytville silty clay loam in Ohio.

Conservation tillage of continuous corn frequently produced lower grain yields than moldboard plowing on a poorly drained Chalmers silty clay loam with high organic matter in Indiana, on a moderately well-drained Kenyon silt loam in northeastern Iowa, and on somewhat poorly drained to poorly drained clay loam soil in southern Minnesota. However, grain yields of long-term continuous corn grown using no-till, ridge till, and chisel plowing on a poorly drained, low-organic-matter Clermont silt loam in Indiana were equal to yields obtained with moldboard plowing. No-till corn yields improved with time relative to moldboard plowing yields on the Clermont soil, which crusts easily under moldboard plowing. However, no-till yields decreased with time on the Chalmers soil relative to moldboard plowing (Griffith et al. 1988).

In the southern Minnesota study, clearing residue from the seedrow increased continuous corn grain yields over those obtained in mulch-covered no-till plots. Plots managed with ridge tillage generally produced higher continuous corn yields than those where residue was removed from a level row area.

High Runoff

High runoff often occurs on sloping soils that have surface layers with low infiltration rates. These soils include those with compacted surface layers from traffic or natural conditions and those which crust easily from rain. Examples include soils with low organic matter content and silt loam textures similar to those found at Coshocton, OH.

No-tillage has the potential for increasing infiltration under many conditions (Edwards 1982). It tends to increase the organic matter content of soil at the surface. By leaving all crop residues on the surface, it often increases populations of surface-feeding earthworms, whose burrows allow rapid infiltration when water begins to pond on the surface. In studies at Coshocton, OH, the preservation of continuous microchannels in the soil and the retention of crop residue reduced runoff in no-till corn to 5 percent of that in a nearby watershed with conventionally tilled corn.

However, differences in soils and weather patterns, the presence of effective macropores, and management and mulching practices can all determine how much a no-till system decreases runoff. If climate and soil conditions exclude extensive earthworm activity, traffic can cause unrelieved reductions in infiltration and increase the runoff with no-till, particularly in the early years before organic matter builds up in the surface soil.

For example, after 10 years of continuous corn on a clay loam prairie soil in Minnesota, runoff of water applied at a rate of 5 inches/hr in tracked and untracked interrows was greater in no-till plots than in untracked interrows of freshly cultivated plots that were chisel plowed or moldboard plowed the previous fall. Similar results were obtained on a low-organic-matter silt loam soil in southwestern Wisconsin. Here infiltration rates were measured 1 hour after initial runoff on unweathered surfaces following planting; 10-year averages were 1.7 inches/hr for no-till with double residue and 1.3 inches/hr for the spring moldboard plow treatment. When the no-till surface was fractured by nitrogen injection, the infiltration rates increased dramatically.

The hydraulic characteristics of the subsoil affect infiltration when the profile is nearly saturated but are less important at other times. If the soil surface is sealed or consolidated and its infiltration capacity is low, runoff will be high unless the surface is fractured by tillage or the condition is alleviated by wetting and drying or earthworm or other soil faunal activity. On a soil with good internal drainage at Coshocton, OH, most of the annual runoff from plots of conventionally tilled corn grown in rotation occurred during the summer months when high rainfall rates exceeded infiltration rates into the crusted surfaces. On this same soil no-tillage greatly reduced the runoff from summer storms on continuous corn watersheds.

This site had little runoff during the dormant season because the low-intensity precipitation of winter storms did not exceed the infiltration capacity of surfaces protected by crop residue. However, on soils with limited internal drainage, considerable runoff during the dormant season does occur—even with low-intensity precipitation—because the soil is saturated above subsurface horizons. No-tillage reduced summer runoff in Coshocton; crop water use maintained the storage capacity for infiltration of rainfall. High erosion rates are usually associated with runoff from high-intensity summer storms, so no-tillage may reduce erosion more than it reduces runoff on poorly drained soils (Edwards and Amerman 1984).

Drought Stress

Corn yield response to tillage is related to soil drainage, with reduced tillage often producing a yield advantage on better-drained soils (Griffith et al. 1992). No-till corn yields often improve on well-drained soils in the southern portion of the North Central Region. Conservation tillage in western Iowa was estimated to increase corn yields 12 bu/acre, compared with conventional tillage when spring soil moisture in the root zone was 50 percent of plant-available water-holding capacity; conservation tillage was estimated to increase grain yield 25 bu/acre when spring soil moisture was only 20 percent of plant-available water-holding capacity (Miller and Schrader 1976). Other research in northwest Iowa found that in years when water stress reduced conventional corn yields, tillage practices that conserved water increased grain yields. In these and similar studies during drought years in drier portions of the North Central Region, water conserved by tillage practices and crop residue usually has a greater effect on grain yield than the reduced, low soil temperature in early spring.

Effect of Rotations and Climate on Crop Residue and Stored Water

The previous crop determines the amount and kind of residue present, and climatic conditions determine how rapidly the residue decomposes. Residues such as cornstalks, which are large in diameter and low in nitrogen, remain longer than corn leaves or than crop materials that are well supplied with nitrogen, such as soybean leaves or alfalfa residue.

Decreases in corn yield following alfalfa are well documented under conditions of insufficient water—a common condition in the western part of the North Central Region. Under such conditions use of legume green manure crops for nitrogen fixation is restricted by climatic conditions (Shrader and Voss 1980).

In Wisconsin, yields of unirrigated corn planted into perennials such as alfalfa or alfalfa-grass mixtures depended on the time of year the cover crop was killed and on spring rainfall. The soil was commonly drier at corn planting when the alfalfa was killed in the spring due to the alfalfa's water use (Smith et al. 1992). The water use by spring-killed alfalfa also (1) reduced the germination and early growth of corn—effects most likely to occur in springs with below-average precipitation, (2) reduced corn population in three of six farm trials, and (3) increased grain moisture an average of 3 percent. When no-till corn was grown after spring-killed perennials, corn emergence was delayed 1.5–4 days, corn development was delayed throughout the growing season, and grain yield suffered a reduction of 10–50 percent. No-till corn planted in fall-killed alfalfa had yields equal to yields from conventional-tillage corn.

In Wisconsin, spring-killed pure alfalfa stands gave greater protection from soil erosion from water than fall-killed pure alfalfa did, because the fall-killed alfalfa decomposed over the winter and did not provide spring regrowth. A cover crop killed in the spring usually offered more surface residue (60–90 percent cover) than a fall-killed crop did (40 percent cover). With alfalfa-grass mixtures where the last cutting is left standing the previous fall or significant regrowth occurs before frost, late fall killing usually provides soil protection and avoids depletion of soil water the following spring.

Crop Residue as a Conservation Measure

Laflen et al. (1985) describe soil conservation practices as components of a soil-erosion-control system. These practices include conservation tillage, sod-based rotations, contour farming, stripcropping, terracing, grassed waterways, underground outlets, water and sediment basins, and vegetative cover. The objective of a soil-erosion-control system is to reduce rill and interill erosion to acceptable levels, transport runoff water to an outlet in a nonerosive manner, and deposit eroded soil before water enters the transport system.

Although crop residues are effective, there are physical limits to the degree that unanchored surface mulches can control soil erosion. Mulch may give way under the concentrated water flows that accompany intense rainfall events. A no-till system leaves more surface residue that is anchored better in the soil and allows soil to retain its cohesion and resistance to detachment and transport by flowing water. These effects are illustrated in concentrated flow areas on mulch-tilled land after intense storms. In such instances where erosion carries away soil to the depth of tillage, the more cohesive untilled soil, which forms the bottom of the channel, successfully resists detachment. These are important differences between no-till and mulch tillage that are not accounted for by residue cover factors alone.

Researchers found increased infiltration and surface storage with contoured rows, which resulted in less runoff. Other research found soil losses decreased up to 74 percent by planting on the contour. However, as surface drainage networks became established that crossed the contoured rows, the differences diminished between erosion on contoured plots and that on up-and-down-hill plots.

Data obtained on natural runoff from plots in Morris, MN, show the variation in soil erosion hazards over years. Over a 10-year period, average annual soil loss was 15.4 tons/acre for fallow, 7.1 tons/acre for continuous corn, 3.4 tons/acre for corn in rotation, and 1.8 tons/acre for oats in rotation over a 10-year period. The rotation was corn-oats-alfalfa hay. Tillage and planting were performed up and down slope. Annual soil losses for continuous corn grown on a 6-percent slope was within the soil-loss tolerance level for 7 of the 10 years; soil losses exceeded the tolerance level for 3 years. But in 1 of the 10 years, the soil loss exceeded the entire loss of the other 9 years combined.

Soil-loss data obtained over a 24-year period in Kingdom City, MO, showed similar results. About 60 percent of the total soil loss occurred in 2 of the 24 years. These data raise significant questions: Should conservation systems be designed to control soil loss from the effects of climatic conditions over the long term, or should they be designed to protect against excessive soil loss from significant storm events that occur less frequently, such as the heavy rainfall of 1993 in much of the North Central Region?

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17 Long-Term Effects of Tillage and Crop Residue Management

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The Beginnings of Soil Degradation

When Europeans arrived in America, they found largely virgin soils that were a result of the climate and vegetation interacting with the geologic minerals. Leaves and other residues fell to the ground and decayed, and part of their decomposition products leached into the soil. Roots grew, died, and decayed, also contributing to building the organic matter and associated elements that nurtured the natural successions of plants. Among these plants were legumes that provided photosynthate to bacteria infecting their roots, and these roots were able to take nitrogen out of the air, fix it in ammonium, and share it with their host plants. Primarily as a result of these legumes, about 6 percent of the residual organic matter in soils is now nitrogen. Other plant nutrients extracted from the soil and air and incorporated into the plants also became part of this soil organic matter.

While most native Americans were crop growers, they were few in number. Their methods of crop production involved little tillage. Competing weeds were removed largely by hand. Friendly natives taught the newly arrived Europeans how to grow corn in the early part of the 17th century. With their iron mattocks and hoes, the Europeans were able to control weed growth more efficiently than the natives. Within a few years corn was the staple of their diet, and they were growing enough corn to trade it to the natives for animal furs. The arrival of draft animals, cultivators, and plows gave the Europeans additional ability to control weeds. These implements also stirred and aerated the soil, buried crop residues, and stimulated microbial activity, which increased the breakdown of the residual organic matter, liberating its nutrients for use by the crops. Since there were no commercial fertilizers, this accelerated decomposition of organic matter was the primary source of plant nutrients in those early years.

In the 19th century, John Deere developed the moldboard plow, which turned the soil over completely, burying practically all of the crop residue, and became the most popular implement for primary tillage. Complete burial of the crop residue and decreasing residual organic matter exposed soils to the beating action of raindrops, which destroyed soil aggregates, filled the large pores, and reduced infiltration, causing runoff and erosion. Erosion by runoff water carried away substantial portions of the topsoil in the eastern and southern portions of the country where rainfall rates were high. In the more arid western plains, burial of plant residues and subsequent beating from rain created smooth surfaces. The wind blew the sand grains along these surfaces until they literally sandblasted the soil, enabling the wind to blow away major portions of our topsoils

Early in the 20th century concerned farmers and government officials recognized the rapid degradation of our soils from erosion and initiated research and made plans to reduce erosion. In the 1920's and 1930's, rotations, stripcropping, and mulch tillage were evaluated. These techniques involved chisels and blades that sliced under the surface and killed weeds but left most of the wheat stubble on the surface. They obviously helped reduce wind and water erosion. It took longer to observe their effects on soil organic-matter content and fertility.

Long-term studies were initiated at several locations across the country. In 1876, at Urbana, IL, the Morrow experimental plots were established by Manley Miles and George E. Morrow to measure cropping effects, and they have been operated continuously ever since (Odell et al. 1984). They indicate that soil organic matter was over 6 percent when European Americans began tilling them. Continuous corn, involving plowing each year, has reduced the organic matter content to less than 3 percent (fig. 11). The best rotations reduced the rate of depletion; legumes in those rotations helped maintain soil fertility, but levels of organic matter still continued to decline as long as plowing continued.

At Pendleton, OR, on grassland where tillage began in 1881, the organic matter content in residual soil under grass was also decreased under moldboard plowing, which accelerated runoff, erosion, and loss of fertility. Consequently, in 1929, researchers began evaluating a series of crop residue management treatments, ranging from burning the residues to plowing 10 tons of manure plus the crop residues into the soil each growing season. Refraining from burning slowed the decline of residual organic matter, and during the first 20 years the heavy manure addition preceding each crop seemed to slightly increase the organic matter content (fig. 12). However, over the past 40 years even, with 11–12 tons of organic residue plowed into the soil each growing season, residual organic matter content has not increased (Rasmussen et al. 1989).

Reicosky and Lindstrom (1993) measured the carbon dioxide given off in fields for 19 days after wheat stubble was moldboard plowed, chisel plowed, disked, or left standing with no-tillage. As shown in figure 13, the amount of carbon oxidized was greatest in fields that were moldboard plowed. In 19 days as much carbon oxidized as had been photosynthesized and incorporated into the residues and roots during the whole growing season. A large portion of the crop residue had not completely decomposed at the time. Consequently, it appears that easily decomposable portions of the fresh residue provided food to generate high microbial populations, which found access to residual organic matter in the plowed and highly aerated soil and oxidized substantial amounts of it out of the soil. When one realizes that microbes can oxidize a couple of tons of organic matter in 19 days following moldboard plowing, it is easy to see how the 12 tons plowed into the Pendleton, OR, plots could be oxidized each crop year for the past 40 years.

Other types of tillage resulted in lower biological oxidation rates than moldboard plowing (fig. 13). Their use is helping slow the rate at which residual organic matter is being oxidized out of our soils. However, during the 19-day study period, oxidation of organic matter from all of the tillage treatments was much more than that from the no-till treatment.

Effects of Reducing Tillage on Residual Organic Matter

Development of wide v-blade sweeps, rod weeders, and other equipment that disrupt the soil and undercut weeds while leaving most of the crop residue on the surface helped control erosion (Lindstrom et al. 1974). As relatively low-cost fertilizers became available in the late 1960's and early 1970's, however, it was no longer necessary to till and oxidize organic matter to release needed nutrients. Development of herbicides provided an alternative to tillage for weed control. As conservation-minded researchers and farmers saw the improved erosion control that leaving residues on the surface gave, they used these alternatives and reduced tillage. Some of them reasoned that growth of grain crops was now possible in systems more similar to those in natural ecosystems.

In these natural systems when vegetative growth is good and burning does not occur, the soils generally have continuous cover and protection from the forces of wind and water. The major obstacle remaining was getting seed through the surface residues and into the soil. Equipment companies helped develop coulters, seed placement devices, and press wheels that cut through the residues without disturbing them appreciably and pressed seed into good contact with the soil. Development of no-till drills and seeders provided an alternative to seedbed preparation, the other major purpose of tillage. With these alternatives available, thousands of fields were soon managed without tillage.

The erosion control benefits of no-tillage were immediately obvious. Researchers documented that no-till reduced erosion to less than 20 percent of that occurring under moldboard plowing systems and in many fields even eliminated it completely. By removing crop residues from some of their no-till plots and observing erosion during rainstorms, they found that absence of tillage, in addition to keeping protective residues on the surface, leaves the soil more cohesive and more resistant to the erosive forces of water. Measurements in laboratories showed that bonding forces between soil particles decrease with tillage and increase with time following tillage. Root fabric and the high residual organic matter content that develops in the immediate surface under no-till reduce slaking and disintegration of aggregates when wetted.

In the past, scientists felt that incorporating crop residues was the way to get organic matter into the soils where it could become part of the residual organic matter. Reicosky and Lindstrom (1993) showed this intuitive feeling was wrong. In fact, incorporating crops residues into the soil by moldboard plowing accelerates the rate of oxidation of both the crop residues and the residual organic matter, as discussed previously.

Farmers practicing no-till management are noticing their soils becoming darker and richer. In Ohio, Georgia, Alabama, and Colorado measurements showed residual organic matter in no-till soils to be increasing. This increase has been greatest in the surface 2 inches, the zone most important for reducing slaking and for surface sealing (see fig. 10, p. 72) (Eghball et al. 1994). When no-till management was practiced for 10 or 20 years, the residual organic matter in the top inch of soil could increase to over 10 percent (Edwards et al. 1988). However, there was little change below 3 inches. Minor tillage such as light disking mixes the organic matter deeper into the soil but also causes more rapid oxidation of the organic matter (fig. 14) (Wood and Edwards 1992).

Effects of Increasing Surface Residues on Residual Organic Matter

Measurements of residual organic matter in soils during 10 or more years of no-till management indicate increases ranging from 200 to 1,500 lb/acre/yr. The rate depends on how much crop residue is left on the surface. The highest rates occur where crop residues were augmented with winter cover crops left on the surface (Langdale et al. 1992b). The lower rates were found in dry, warm regions where the amount of crop residues was limited and high temperatures caused rapid biological oxidation of the organic matter.

In areas where residual organic matter is low, organic wastes such as paper and manure have been placed on the soil surface or plowed into the soil to help increase the organic matter. The greatest sustained increases are occurring where there is no tillage and the organic wastes are left on the surface (Lu et al. 1994, 1995).

Elimination of tillage increases the amounts of organic residues on soil surfaces, decreases the biological oxidation rates of residual organic matter, and reduces soil erosion, all of which cause net increases in residual soil organic matter. No-tillage and reduced tillage can conserve our soils, and they can also enhance them so they will be able to sustain the world's population.

Effects of Leaving Crop Residue on the Surface

Effects on Soil Fertility, pH, and Rooting Depth

Soil fertility. One early concern about no-tillage was getting fertilizer and lime from the surface down to the crop roots. To some extent feeder roots solved this problem by nearing the surface where the soil was moister because crop residues reduced evaporation.

Phosphorus was also expected to be a problem because it is normally adsorbed and relatively immobile in soils. However, as Kunishi et al. (1986) found, it apparently forms complexes with surface organic matter, and these leach into the underlying soil where they are readily available to feeder roots. Through mycorrhiza—the beneficial association of fungal mycelium with the roots of a plant—fungi extend their slim hyphae into the soil and allow plants to draw phosphate from those parts of the soil their roots cannot directly reach. More of these hyphal conduits remain intact when tillage does not occur. Crop roots in no-till soil tend to follow root channels of the previous crop; this enables the supplemental hyphal system to tie in more quickly, which helps the roots extract water, phosphorus, zinc, and many other elements from the soil (Vivekanandan and Fixen 1991).

To take advantage of the growth potential offered by the additional water conserved under minimum or no-till systems, producers need to add nitrogen, some of which will be incorporated into the increasing soil organic matter. For example, to increase organic matter at a rate of 800 lb/acre/yr, one must add about 40 lb/acre of nitrogen by way of legumes or fertilizers. This addition represents a significant cost inherent in new no-till systems. However, it is an investment that eventually pays dividends by providing a slow, sustained nitrogen supply once nitrates are leached from the root zone by heavy rains. Release of this reserve nitrogen from the residual soil organic matter synchronizes to some extent with the needs of the crop, since high soil temperatures increase both crop growth and mineralization of organic nitrogen through microbial activity.

pH. Calcium has historically been observed to stay close to lime placements in soils, raising questions about whether lime applied on the surface would stay there and leave the underlying soils excessively acid. Some of the early no-till researchers found the immediate surface of no-till soils was becoming acid sooner when urea and ammonium-type fertilizers were broadcast on the surface. Lime broadcast on the fertilized surface seemed to move into the soil more quickly. In long-term no-till fields where lime, crop residues, manure, and nitrogen fertilizer were left on the surface for 24 years, the acidity of underlying soils was neutralized to a depth of about 70 cm (28 inches), compared with about 25 cm (10 inches) where soils were plowed and lime was mixed in (Edwards et al. 1988) (fig. 15). The mechanisms that mobilize the calcium in the lime are probably influenced by the proximity at the surface of the crop residues, the nitrogen fertilizer, and the lime. As microorganisms nitrify ammonium fertilizers to nitrates, acid hydrogen ions are produced that tend to solubilize the calcium in lime when it is close to the fertilizer. The slow and relatively continuous biological breakdown of the surface residues produces a continuous source of organic anions, which along with the nitrates facilitate downward leaching of the positively charged calcium, aluminum, and hydrogen ions in the soil. Researchers have been trying to get more calcium into subsoils for years, because they recognize that a higher pH caused subsoils to be more hospitable to roots. Deep plowing and mixing lime into the subsoil work but are too expensive. These benefits can occur as a side effect of no-till as it leaves all the residues, fertilizer, and lime on the surface. When the nitrogen fertilizer is knifed into the soil, subsoil pH tends to increase, but this moderation of acidity is not as great as that noted when nitrogen fertilizer is applied on the surface.

Rooting depth. Sumner (1990) was able to increase alfalfa rooting depths in acid soils by 50 percent by getting calcium into subsoils with gypsum applications that left the subsoil undisturbed. Wang et al. (1986) found that earthworm burrows in the soil facilitated deeper rooting of soybeans. Since long-term no-till management generally increases earthworm populations and depth of calcium penetration, it's reasonable to think that these two factors probably act together to facilitate deeper rooting. Deeper rooting gives the plants access to more soil water. This access may help account for the increased drought tolerance of crops grown under long-term no-till management on fields that initially had acid subsoils.

To take advantage of the greater growth potential from the additional water conserved, additional fertilizer is commonly needed during the first few years of no-till. The quantity of nitrogen fertilizer needed may decrease after several years in minimum-till and no-till systems as the residual organic matter becomes sufficient to supply more nitrogen for plant use.

Effects on Infiltration, Evaporation, and Water-Use Efficiency

The most direct and measurable effect of keeping crop residues on the soil surface is improving the water-use efficiency of acid and calcareous soils. In many areas the increases in infiltration rate and decreases in evaporation occur within 1–2 years, as discussed in previous chapters. However, in soils where earthworm populations have been decimated by intense cultivation or harmful pesticides, it may take many years to bring the earthworm populations back so their burrows to the surface contribute significantly to infiltration.

In a series of small watersheds near Coshocton, OH, it took earthworms 6 or 7 years to return in large numbers after the beginning of no-till management (Norton and Schroeder 1987). Data were based on measurements of pores larger than 0.5 mm at the soil surface; earthworms and recent cultivation are commonly responsible for such large pores (fig. 16). Following cessation of cultivation, the percentage of the surface occupied by these large pores declined for 5 years. Only when the earthworms returned in large numbers did their burrows furnish the large pores that contribute to rapid entry of water in this soil.

Return of worms has been hastened by collecting buckets of them from lawns and edges of rural roads during or immediately following rains and depositing them in groups of four or five in new no-till fields (James Kinsella, personal communication, 1994). They will invade a soil at a rate of about 50 ft/yr when conditions are good for their growth. However, their lack of a specific urinary tract leaves urea on their skins, which hydrolyzes to ammonia and irritates them. Consequently, they are attracted to moist soils where they can quickly rub off the urea and ammonium and to the surface during rainfall events where the rain washes them off. Their tendency to come to the surface during rainfall events contributes to their migration during runoff, when they float downhill. On cloudy days when canopy cover is reasonably complete and at night, earthworms have been seen floating in tailwater out of furrow-irrigated fields in Idaho at rates of up to 50/hr/furrow. In runoff plots at Kingdom City, MO, as many as 900 earthworms washed off a 945-ft^2 plot in a single rainfall event. While average rates of downstream transfer are generally lower than those given in these examples, introducing worms on the higher portions of a field can significantly increase their rate of return to the whole field.

As soon as crop residues provide cover for most of the surface for a significant part of the year, they help reduce evaporation from the soil. Long-term no-till growers report the amount of crop residue returned to the field increases with time for 10 or more years as crop yields increase. However, some long-term no-tillers note that large populations of night-crawler-type earthworms collect residues in their middens, especially after soybeans, causing a more-rapid-than-normal removal of cover from the soil. Fortunately, this process does not usually reduce cover until the crop canopy has already begun protecting the soil from the impact of raindrops. Even when lack of cover allows a major portion of the soil surface to seal, several earthworm middens or holes per yd^2 drain most water accumulating on the surface into the soil, minimizing runoff.

Another long-term effect of keeping residues on the surface and one that contributes to water use efficiency is accumulation of residual organic matter. As discussed earlier this is a slow process, occurring at a rate of about 1,000 lb/yr under good no-till management. A 1 percent increase in the organic matter content of the top 6 inches of soil takes about 20 years. It could take a century of good no-till production to restore the organic matter to the soils in the Morrow, IL, plots from their current content of about 2 percent to their original content of over 6 percent.

Hudson (1994) has shown the available water-holding capacity of loam soils increases by almost 4 percent of the soil volume for each additional percentage of residual organic matter. Farmers whose topsoils have low organic matter and water-holding capacities of 10–12 percent thus have the potential of increasing those capacities up to 14–16 percent in 20 years. If the organic matter buildup and increased water-holding capacity is restricted to the top 6 inches, the soil would hold an extra 1/4 inch of water each time the it dries out and rain refills it. The total amount of extra water held from all the refills over a growing season would only be 1–2 inches, but because most feeder roots are in the top layer, crops gain better access to nutrients, as well as water during drought.

Effects on Crop Production

Factors that increase the units of crop produced per unit of precipitation include significant increases in infiltration, decreases in evaporation from soils, increased water-holding capacity, increased snow catch and deeper rooting associated with no-tillage, and retention of surface residues (Langdale et al 1994).

High residual organic matter in soil also increases general fertility and productive capacity. On three sites in North Dakota, Bauer and Black (1994) quantified the value of soil organic matter to productivity. Each ton of organic matter was calculated to increase yields by 31 lb of grain/acre. If soil loss was 10 tons/acre/yr, then over a 50-year period 500 tons of soil would be lost. If this soil contained an average of 4 percent organic matter, then 20 tons of organic matter/acre would be lost over the 50 years. In this example, the loss in soil productivity therefore would be 20 tons of organic matter multiplied by 31 lb of grain/ton of organic matter, or 620 lb of grain/acre, or 10.3 bu/acre.

Residual organic matter, which derives from plants, includes most of the elements essential for crop production. Its slow decay provides a limited but continuing source of these elements and also furnishes a host of organic molecules or fragments that carry micronutrients absorbed in soil minerals to the roots. Unlike no-till, tillage accelerates the rate at which nutrients from crop residues and residual soil organic matter are mineralized or made available to crops. If the crop is not ready to use the nitrates, they are at risk of being leached out of the crop zone by rain. Like stirring the coals, putting in kindling, and opening the draft of a wood stove, tillage accelerates the oxidation of organic matter, liberating its components quickly to the surrounding environment.

Organic matter darkens soils because they absorb more of the sun's radiation, and soils that absorb more of the sun's radiation are warmer. Because crop residues reflect more of the radiation, covered soils stay cooler, which decreases plant growth in the cool early spring but may be better for crops in the late spring or early summer.

Cooler spring temperatures under mulches, outbreaks of disease and insects in monoculture, and occasional lapses in weed control all can reduce yields on fields where residues are all left on the surface. However, on most soils the long-term benefits of no-till generally result in greater productivity as time progresses than tilled fields do (fig. 17).

Effects on Erosion Control

Increased residue cover achieves substantial erosion control by (1) intercepting the impact of raindrops, slowing surface sealing, and sustaining higher infiltration; (2) causing water to pond on the surface, which causes wormholes and other macropores to become avenues for infiltration; and (3) causing settlement of sediment in the temporarily ponded water (Langdale et al. 1992a, 1994).

Reasons for Limited Tillage

Reasons for using limited tillage include the following:

- In some cases the cost of one form of a nutrient, such as the anhydrous form of ammonia, is sufficiently lower than the cost of another nitrogen fertilizer to economically justify the limited cultivation needed to incorporate this gas.
- Deep chiseling or paratilling of soils to help crop roots grow past restricting layers benefits yields in some areas. Langdale et al. (1992b) found, however, that the layers became less restrictive and the chiseling was no longer necessary after 10 years of no-till and winter cover crops.
- Ridge- or row-till equipment can push residues off the planting strip for row crops, allowing the use of conventional planting equipment and warming the soil to accelerate early growth.
- Under some climatic conditions weed and grain seeds need a light soil cover to help them germinate so they can all be killed by one herbicide application before a long fallow season or before planting the next crop.
- During the initial 2 or 3 years of no-till, before sufficient soil cohesion has developed to support equipment weight, the soil may become so compacted and rutted during harvest in wet weather that tillage is necessary to break up the compaction and smooth the surface. (See chapter 14 for a fuller discussion of compaction.)
- Some state and regional regulations require burial of specific wastes and crop residues to control insects and diseases.

Each farmer must balance these benefits of cultivation against the damages. The benefits to be derived must be large to justify moldboard plowing. Other types of tillage should be considered first when tillage is necessary.

One of the most critical factors that needs to be examined is the degree to which tillage will destroy soil cohesion, crop residue cover, and erosion control as computed by Soil Conservation Service (SCS) guidelines and equations. The economic consequences of failure to be in conservation compliance will be devastating for most farmers enrolled in government programs. Consultation with SCS technicians may help farmers avoid both the loss of erosion control and crop support payments.

Effects of Herbicides on the Environment

Concern has been expressed in some public sectors that long-term use of herbicides for weed control rather than tillage will add manufactured chemicals to our soil, air, and water, thereby degrading them. A broad survey by Bull et al. (1993) indicates that producers who grow corn use about equal amounts of herbicides whether in tilled or no-till systems.

Most farmers recognize that herbicides are often the most cost-effective means to control weeds. In 1990 herbicide use on no-till soybeans averaged about 56 percent higher than that on tilled soybeans, but by 1992 herbicide use on no-till averaged only about 13 percent more than that on tilled soybeans. Long-term no-tillers say they are using less herbicide than when they started and often even less than when they were tilling. Because adoption of no-till is doubling every 3 years and only 25 percent of no-till farmers have 6 years with the system, we anticipate the amounts of herbicides used in no-till farming will continue to decline as no-till farmers gain more experience with this new system.

A factor that plays a significant role in herbicide contamination of water is the use of soil-incorporated (preemergence) versus direct-contact (postemergence) herbicides. Preemergence herbicides are the more common choice of conventional tillers. The most effective preemergence herbicides include chemicals that are mobile (not absorbed) in the soil and persist for long periods before they degrade. Many of the postemergence herbicides are sprayed directly at the weeds, strongly adsorb (adhere) to soil if they miss their target, and rapidly hydrolyze or biologically degrade when they contact the soil. The postemergence herbicides are becoming less expensive and the more common choice for no-till management.

Reduced tillage keeps topsoil on the land and out of streambeds, reservoirs, and lakes. Where no-till increases, better infiltration rates, less flood damage and increased groundwater recharge and base stream flows improve the environment. In monitored watersheds, where surface sealing from conventional tillage caused 10–30 percent of the precipitation to run off, long-term no-till often reduced runoff to negligible levels.

As water runs off, it carries feces from domestic and wild animals, disease organisms, and a host of organic compounds, over 99 percent of which are of natural origin and less than 1 percent of which are of manufactured origin. Surface runoff that enters reservoirs is so heavily laden with contaminants that standard filtration through graded sand beds does not remove them all. Chlorination is commonly required to kill the pathogens before these surface waters can be used for drinking, but chlorination of humic acids and natural organic compounds can increase their carcinogenicity. When reduced tillage enables all precipitation to enter the soil, pathogens and other organic compounds filter out as the water percolates slowly downward, and the water that then enters aquifers is generally of good drinking quality.

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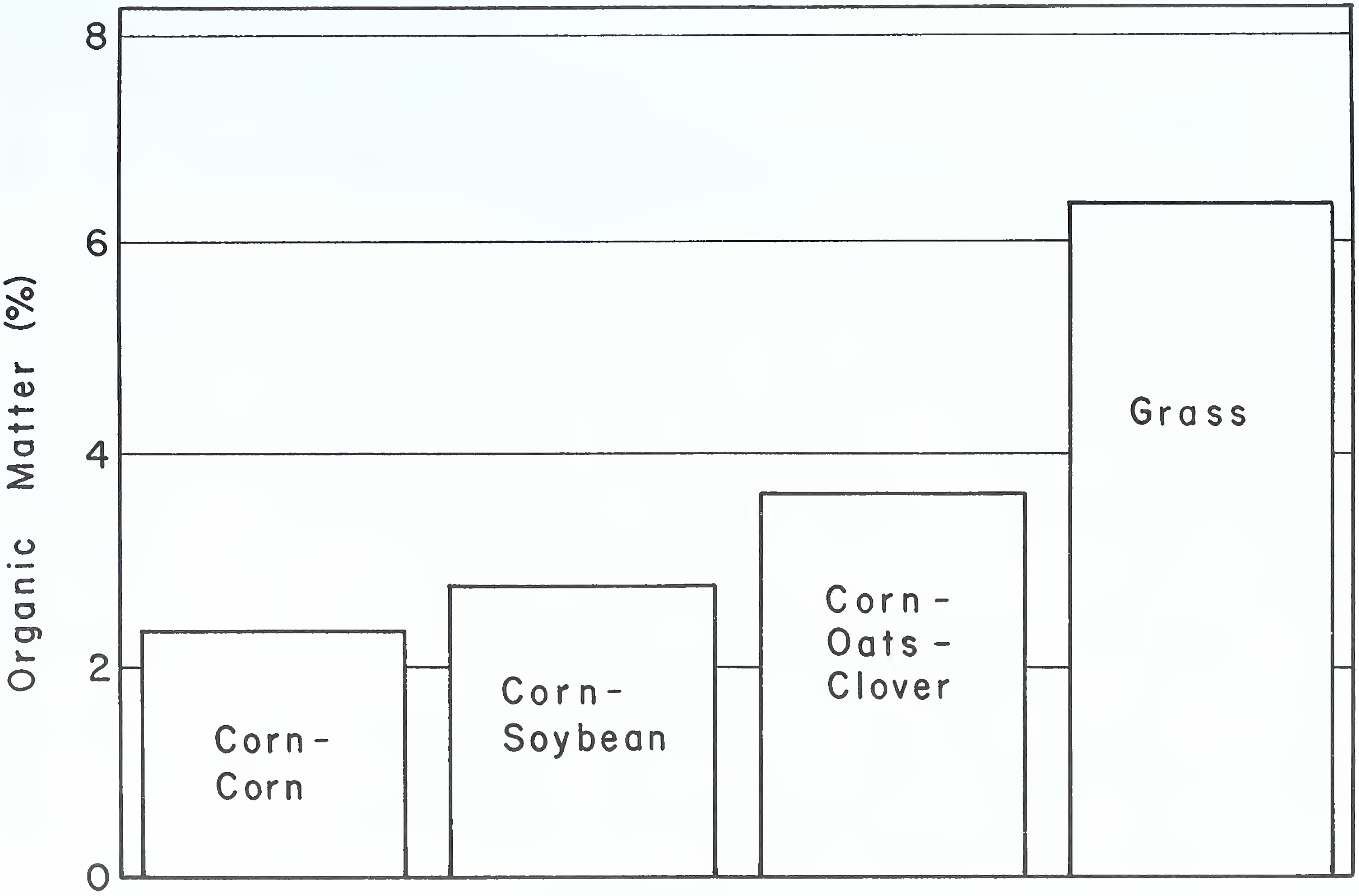

Figure 11. Percentage of organic matter in plowed soils after more than 100 years in various rotations, compared with percentage in untilled soil still in grass. Source: Odell et al. 1984.

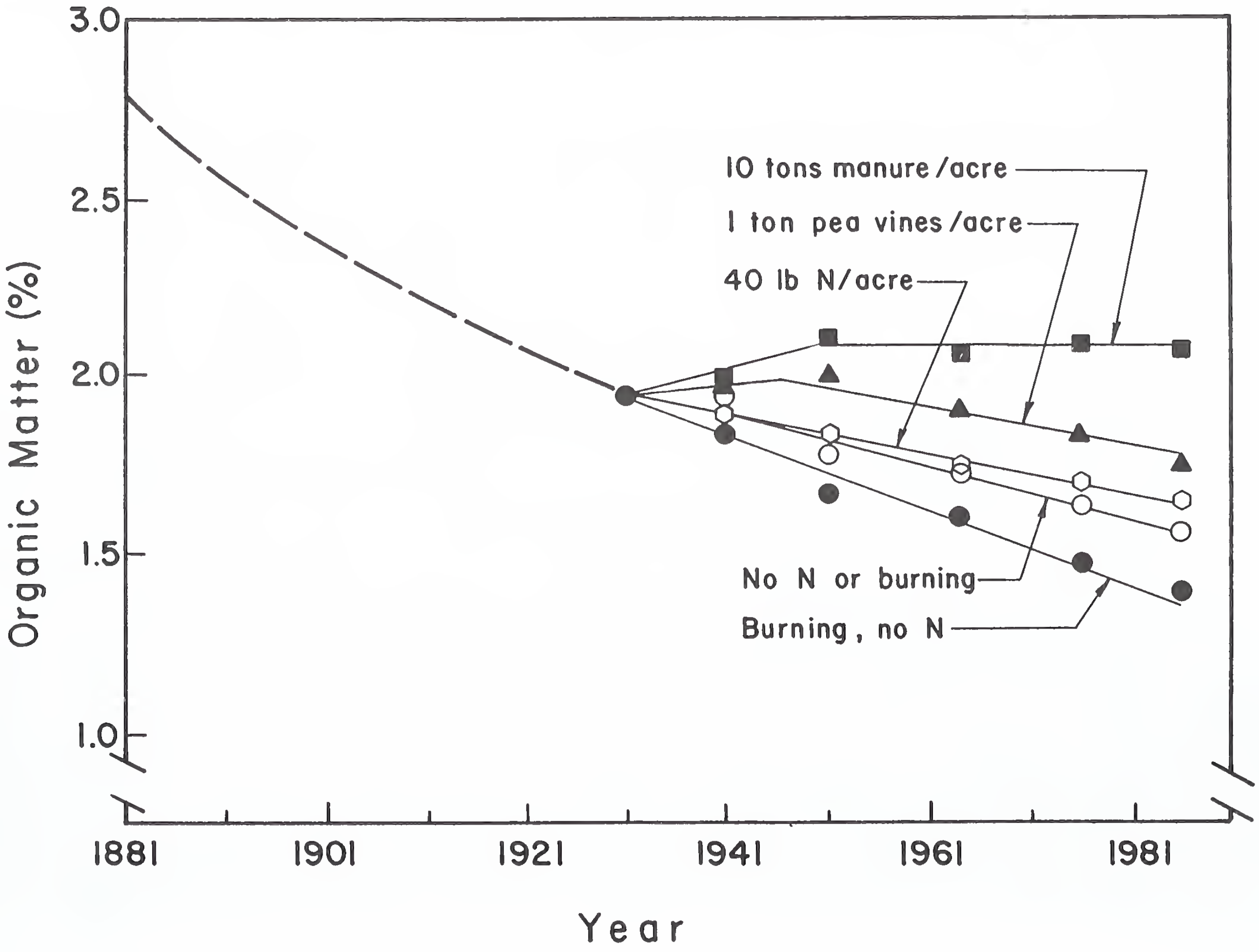

Figure 12. Effect of management practices on long-term changes in organic matter in the top 30 cm of a Haploxeroll soil in Oregon. Source: Rasmussen et al. 1989.

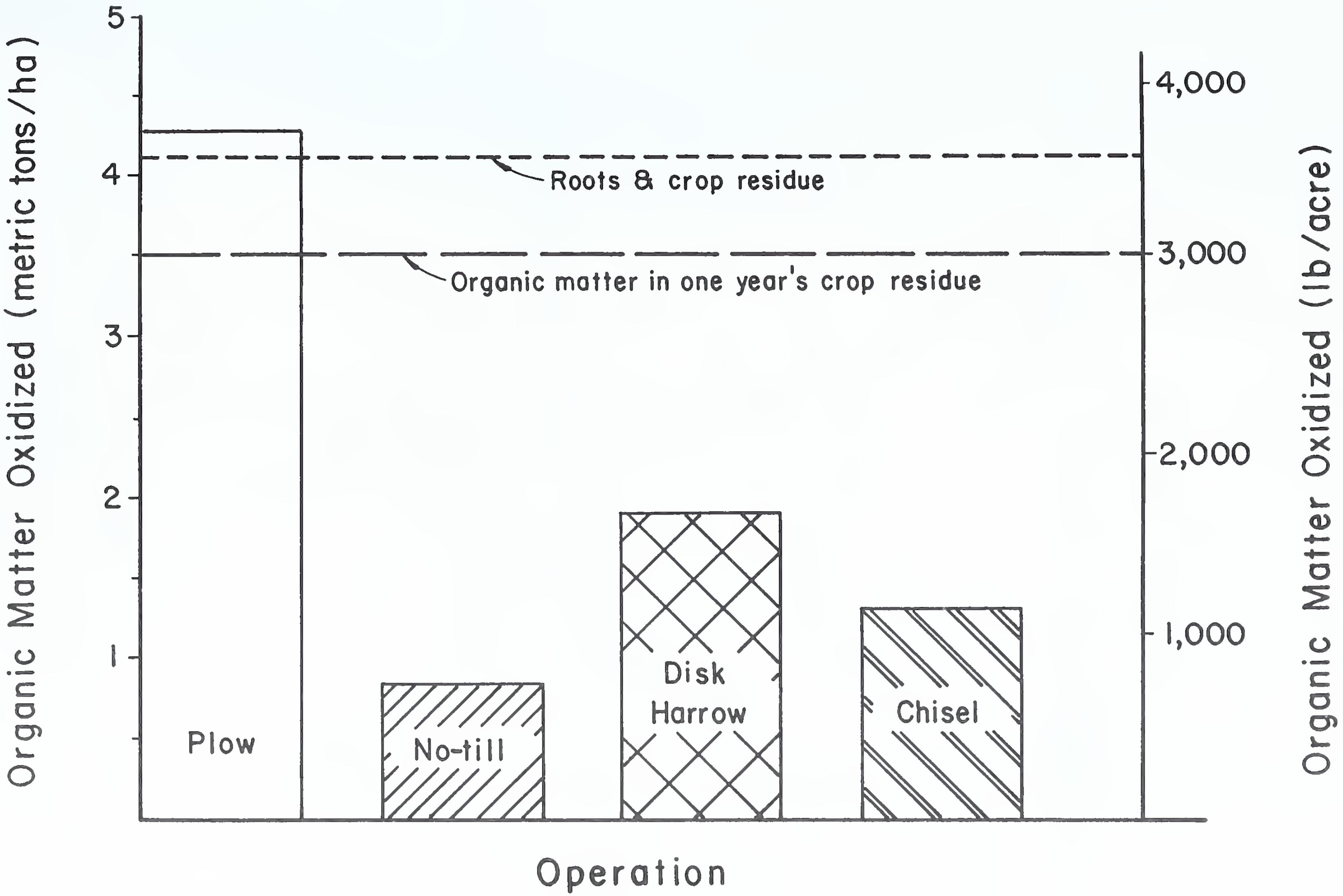

Figure 13. Organic matter oxidized in 19 days in September following various tillage operations on wheat stubble, Morris, MN. Source: Reicosky and Lindstrom 1993.

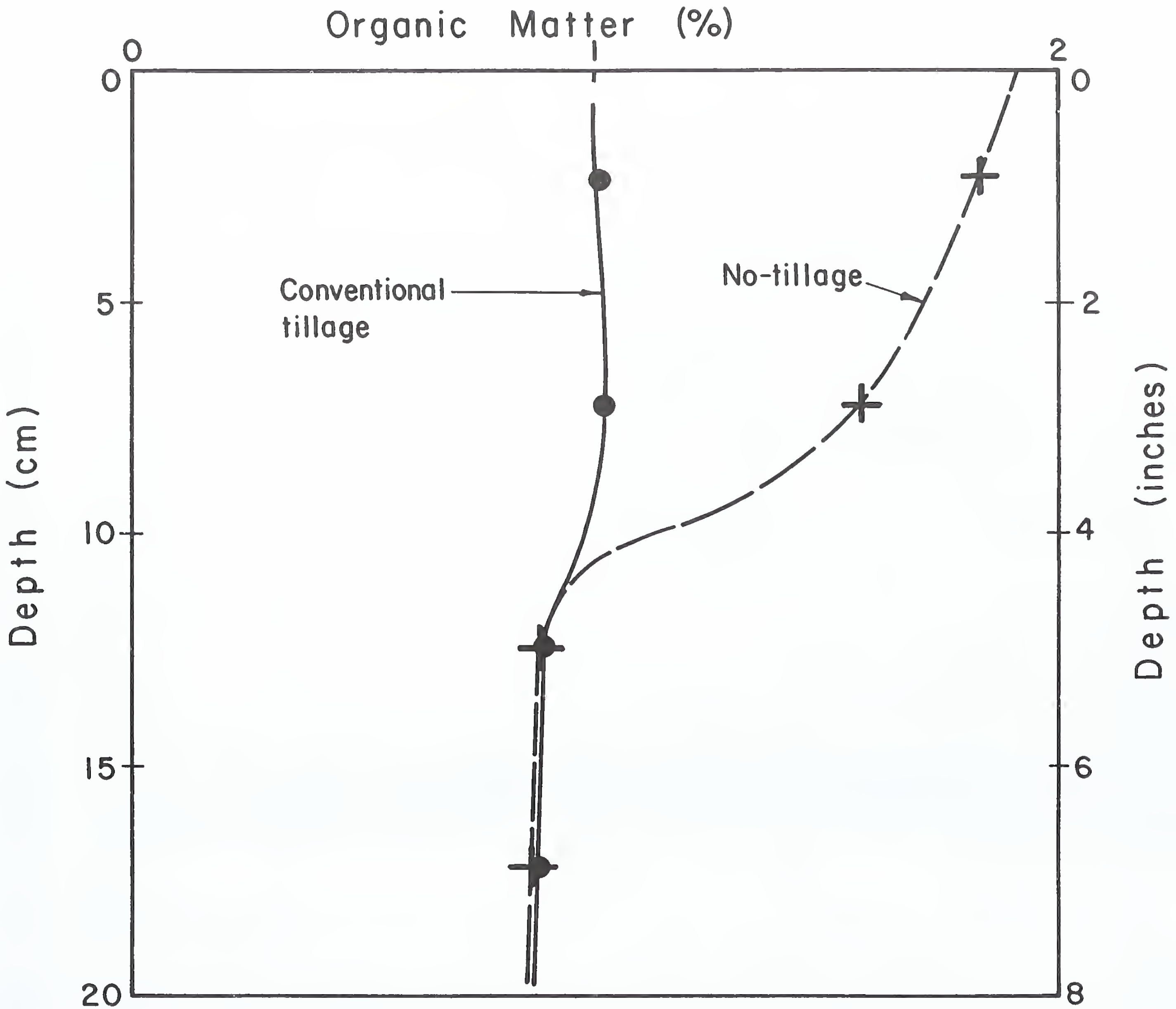

Figure 14. Comparison of organic matter content at various soil depths after 10 years of a conventionally tilled and a no-tilled corn-wheat-soybean-wheat rotation in Crossville, AL

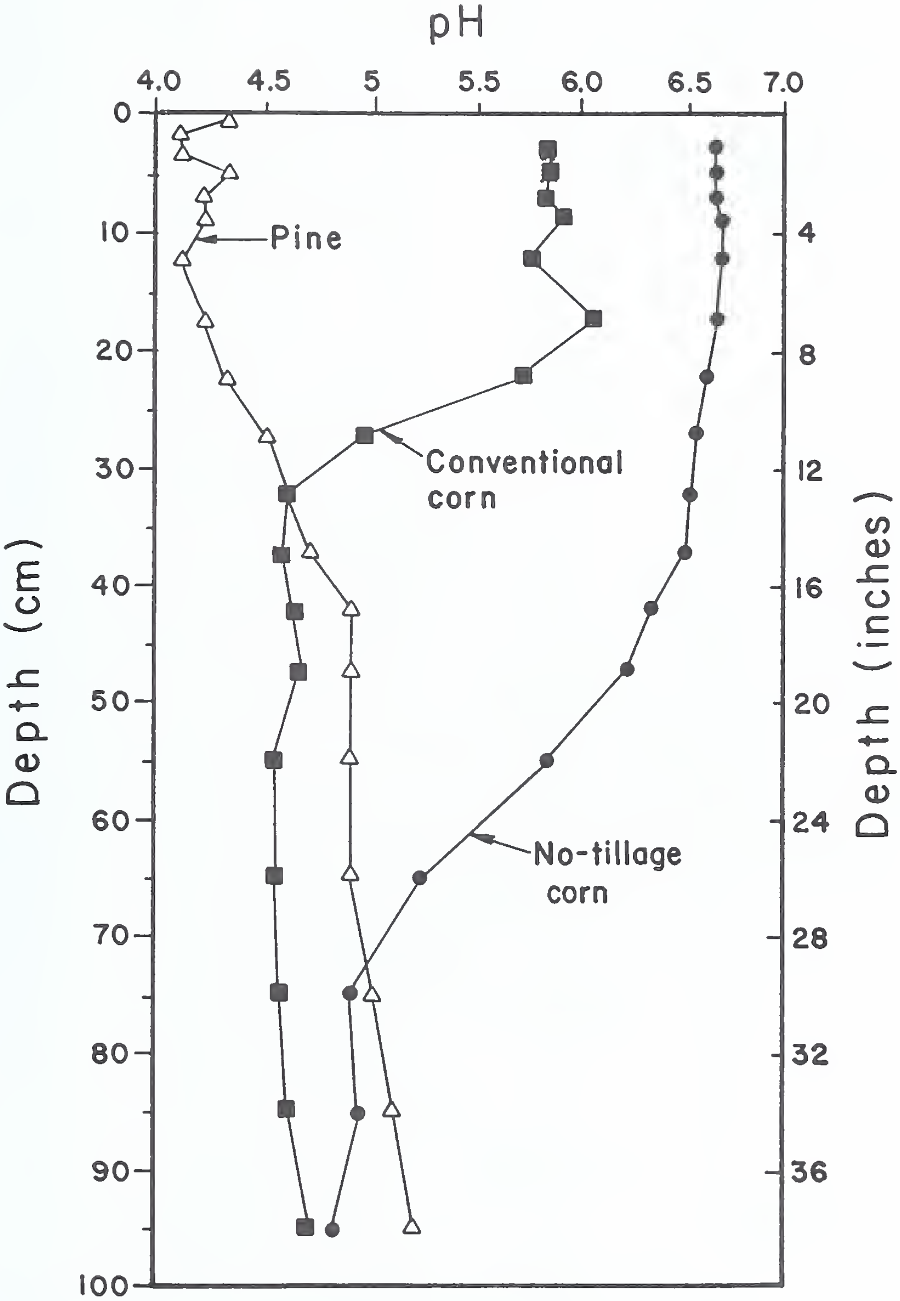

Figure 15. Effect of conventional and no-till management of corn on soil pH at various depths. Source: Edwards et al. 1988.

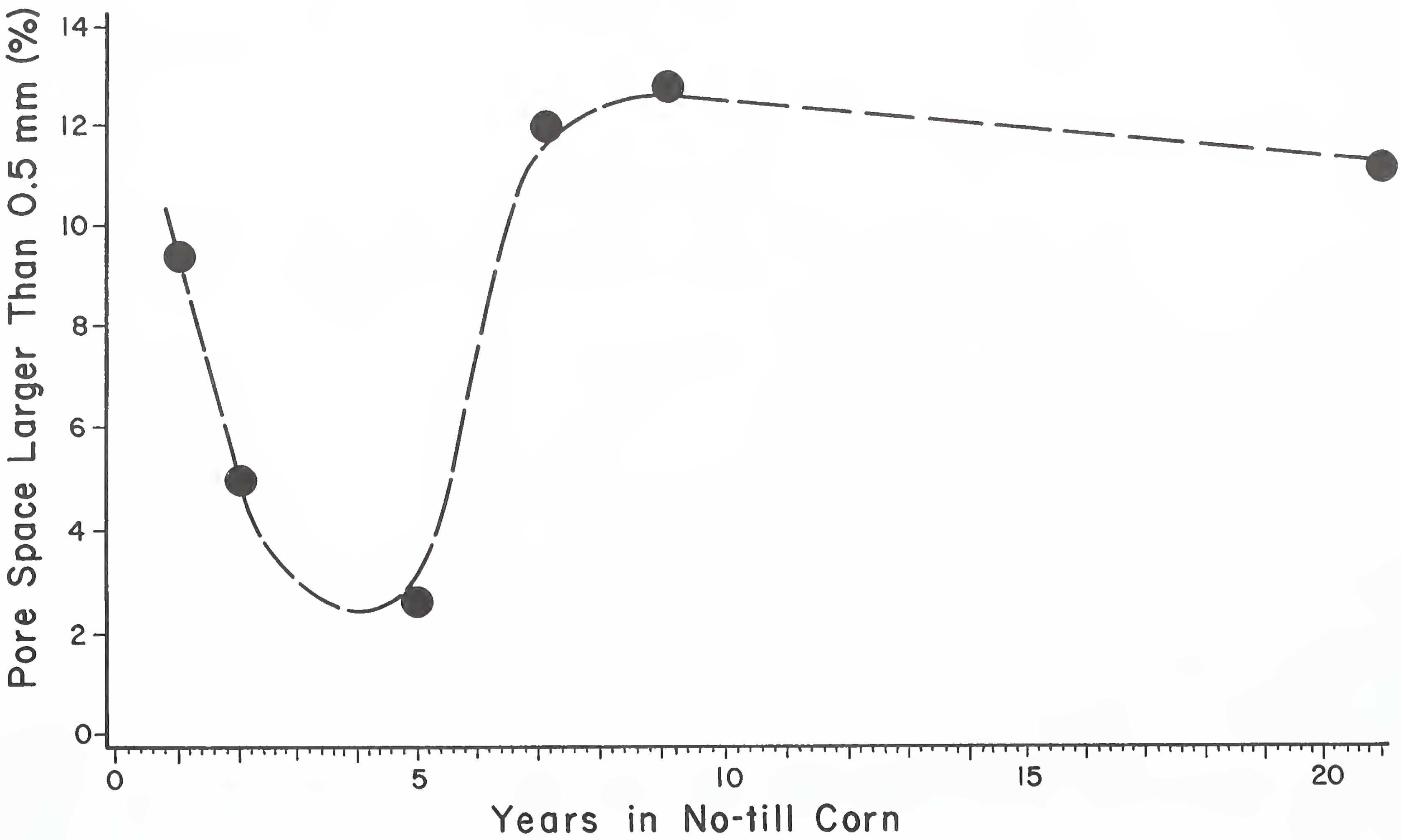

Figure 16. Changes in surface pores larger than 0.5 mm diameter after beginning no-till management, Coshocton, OH. Source: Norton and Schroeder 1987.

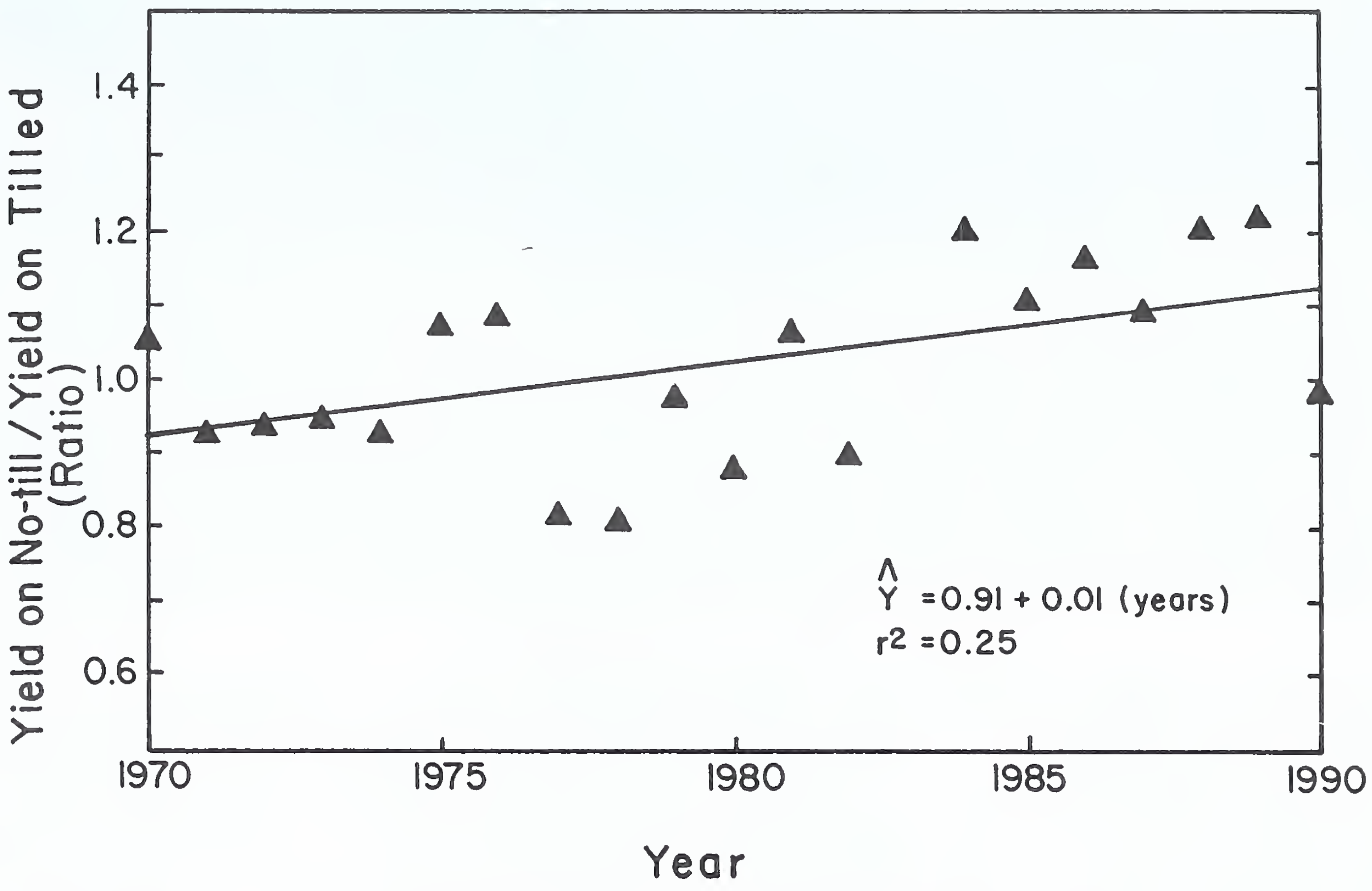

Figure 17. Long-term trends in corn yields under no-till compared with tilled management. Source: Ismail et al. 1994.

18 Management Options After Leaving the Conservation Reserve Program

T.E. Schumacher, M.J. Lindstrom, M.L. Blecha, and L.N. Mielke

Most of the highly erodible lands contracted into the USDA Conservation Reserve Program (CRP) suffered significant erosion, loss of organic matter, and deterioration of soil structure while it was being cultivated. The majority of land enrolled in the program—about 34 million acres—was planted in grass, and as a result, the structure and organic matter level have improved significantly. If these improved lands are tilled again following the program, the improvements will be lost rapidly.

A critical question, then, for land managers of post-CRP land returning to crop production is how to retain the benefits from 10 years of grass. Going directly into no-till can be a cost-effective way to do this. This chapter focuses on the CRP—how grass affects soil properties, the rates at which grass improves soil properties, post-CRP management options, the potential impacts of no-till after CRP, and some basic no-till guidelines.

The Conservation Reserve Program

The CRP was initiated in 1985 under the Food Security Act with the intention of converting up to 45 million acres of highly erodible farmland to permanent ground cover. The rationales for implementing the program included controlling erosion, raising farm prices, protecting wildlife habitats, and improving the national budget.

Under the program USDA pays participants an annual rent for 10 years, plus half the cost of establishing a conserving land cover. To be eligible one had to have land that was potentially highly erodible, actually eroding at an excessive level, or environmentally sensitive. A condition of enrollment was that farmers give up their use of an amount of their commodity-crop base acreage proportional to the amount enrolled in CRP. This relinquished base acreage is returned when the land is retired from the program. The objectives of the CRP have evolved over the course of the program, and new procedures have been developed for selecting lands proposed for the program.

By 1993, 36.4 million acres of highly erodible and environmentally sensitive land were enrolled in CRP. The first contracts will expire in October 1995, and by October 1997, about 24 million more acres will be released. Over half of the acres are located in the 10 Great Plains states. Commodity-crop base acreage was reduced by 23.3 million acres, and erosion was reduced by about 19 tons/acre/yr on average.

As contracts approach expiration, producers are wondering what the future holds for their enrolled land. Organic matter content, soil structure, and infiltration rates have greatly improved because the lands have been retained in grass, but these improvements will be rapidly lost if the lands are tilled, as mentioned previously. Among the available options for landowners are leaving the acres in grass for hay or livestock production, establishing wildlife and recreation enterprises, or returning all or part of the land to crop production. Surveys indicate that over half of the contract holders plan to return their land to cropping. Many of these producers lack experience in dealing with the grass and the large amounts of residue that accumulated when the land was idle.

How Grass Benefits Soil

The important characteristics of soil structure are the size, distribution, and geometric arrangement of the pores. The properties of the pores determine such characteristics as infiltration rate, internal drainage, aeration, water-holding capacity, and plant-water availability. Under a sod cover these characteristics often function at near optimal levels. Soils with the best aggregates for crop growth in the United States are those which have been in grass for many years. They have more organic matter, structural stability, total pore space, and air-filled pore space, as well as higher hydraulic conductivity and infiltration rates than conventionally tilled soils. Soils of long-term grasslands tend to have more pores in the size range that permits crops to extract water than cropped soils do. Populations of earthworms have been observed to be six to nine times higher in established grasslands than in cultivated soils. Earthworm channels connected to the surface reduce runoff and improve infiltration into the root zone.

Soils in long-term grass also show improved mechanical properties, a condition that allows traffic under wetter conditions. Farmers who return fine-textured soils to tillage after a long period in grass observe that the time between the soils' being too wet to till and too dry to till decreases with each year of tillage.

Soil aggregates from North American virgin grasslands are more stable than their cultivated counterparts. Cultivation appears to cause a loss of particulate organic matter that binds small aggregates into larger aggregates. Particulate organic matter, which consists primarily of partially decomposed residue and roots, has a higher decomposition rate than other forms of organic matter, and its maintenance requires frequent additions to the soil. Soils under long-term cultivation return less root organic matter than do virgin grasslands, and this reduction appears to lower the organic carbon and nitrogen as deeply as 18 inches below the tilled zone (Bauer and Black 1981). Grasses that form a sod cover, on the other hand, provide an excellent source of particulate organic matter.

In cultivated soils, organic carbon and nitrogen decrease most rapidly in the tilled zone during the first 10 years and then more gradually, depending on the cropping system and the climate (Bauer and Black 1981, Ismail et al. 1994). The pace of this change parallels that in soil structure, which deteriorates most rapidly in the first 2–3 years after cultivation.

The effects of tillage on soil properties are tied to soil type. For example, cultivation of sand dunes and newly deposited sediments low in organic matter, when coupled with adequate provision of crop nutrients and water, can produce reasonably good crops. When residues of grain crops are all returned to the soil, organic matter content can increase and physical properties can improve. In general, however, tillage degrades mature soils that have substantial organic matter content and good aggregation. Long-term tillage in these soils reduces water availability and aeration within the root zone. Pores that hold water available to crops were reduced 14 percent by 12 years of tillage on a Crowley soil in Arkansas (Scott and Wood 1989).

Finally, grass protects the soil surface from the impact of raindrops and from runoff by temporarily trapping water in surface microcatchments and allowing development of cracks and pores open to the surface.

Soil Improvement From Long-Term Grass

Just as tillage degrades soils, soil structure improves when cropped land is planted in grass, with significant improvement observed in 3–5 years. More time is required for restoration of soil properties to the level found in virgin soil. Mazurak and Ramig (1962) estimated that grass provided its maximum benefits after 10–12 years in a medium-textured soil in Nebraska. Soil aggregate distribution, stability, air permeability, and hydraulic conductivity improved with time in the grass treatments. In a Canadian study the estimated half-life for net improvement in structural stability after the introduction of forage ranged from 4.5 years in a clay loam to 7.8 years in a sandy loam (Rasiah and Kay 1994). A review by Kay (1990) suggests that grass significantly improves soil structural stability for at least 10 years, and then improvements continue more slowly.

How the grass is managed influences its effects on soil properties. Planting hay slows the rate of change in soil structure (Mazurak and Ramig 1962), and haying reduces most of the benefits that a legume, such as alfalfa, brings to the soil nitrogen pool (Haas et al. 1976). Although haying may slow the beneficial effects of alfalfa and grass on soil structure, improvement does appear to continue, as shown by the increased organic carbon and soil aggregate stability evident after 5 years of harvesting grass and alfalfa for hay.

The degree of soil improvement from 10 years of grass is likely to be soil and site dependent. As a rule of thumb, the greater the structural deterioration from past cultural practices the more likely that grass management will improve important agronomic characteristics. Rasiah and Kay (1994) found that structure regenerated more quickly in soils that had higher levels of organic matter and other stabilizing materials when the grass was introduced. As mentioned, soils in the CRP generally fit into the category of degraded soils that are lower in organic matter than surrounding soils. Such highly eroded soils tend to have reduced productivity, degraded soil structure, lower organic matter, and less-than-ideal conditions for root growth (Lindstrom et al. 1992).

Post-CRP Options

Before deciding what to do with their post-CRP land, farmers should evaluate existing and developing markets in their area. For the time being existing commodity support payments will help protect farmers from decreasing prices for supported crops for which they have base acreage allotments. However, the long-term provisions of GATT (the General Agreement on Trade and Tariffs) will reduce those supports.

Following is a list of possible options for farmers:

Maintenance of Grass Cover

- Hay production managed to avoid disturbing nesting birds—by delaying the first cutting, for example.
- Rotational grazing timed so nesting birds are not disrupted and grass is not damaged.
- Wildlife management, such as development of fee-based hunting preserves.
- Contracting with the Federal Government for an annual fee to keep permanent vegetation on environmentally sensitive areas on a long-term or permanent basis.

Return to Cropping

- No-till into sod, using appropriate rotations to manage weeds, pests, and fertility without a dramatic increase in purchased inputs.
- Wide v-blade sweep to undercut sod, followed by no-till planting or minimum-till methods of planting and crop production.
- Moldboard or chisel plow to remove the initial residue, followed by no-till to maintain the surface residue of subsequent crops.
- Conventional tillage, with modification of the tillage system and rotation to fit the conservation compliance plan.

- Grass or grass-legume mixture rotated among fields between the crops and the meadow or in strips to reduce annual rates of erosion.

If contracts cannot be renewed, no-till management appears to provide the greatest potential for achieving reasonable net returns and retaining most of the soil quality attained during the CRP. Making the transition from the CRP to economically and environmentally sustainable production systems is discussed in the section that follows.

No-Till After CRP

Benefits

No-tillage avoids the rapid mineralization of carbon and nitrogen that occurs when grass or crop residues are tilled into the soil (see pages 78–79 and 87, chapter 17). Lamb et al. (1985) measured soil organic nitrogen losses in soil that had been in native grasses and that was then cropped in a winter wheat-fallow system. After 12 years, the nitrogen loss in the top 12 inches was 3 percent for no-till, 8 percent for stubble mulch, and 19 percent for tillage (black fallow). In Kentucky, land that had once been in bluegrass sod showed about twice as much organic carbon and nitrogen in the surface soil layer after 10 years of no-till corn than after 10 years of conventionally tilled corn (Blevins et al. 1983). The organic carbon and nitrogen levels did drop under both tillage systems; however, with heavy applications of nitrogen and lime under no-till the levels could be maintained close to those of the bluegrass.

One of the first changes resulting from intensive tillage involves breaking the continuity of established soil pores. In a permanent pasture that had been lightly grazed, 4 years of cultivation to a depth of 4 inches completely disrupted the many water-transmitting macropores. This disturbance reduced preferential flow within the macropore network and altered the pathway of infiltrated water movement, thereby increasing water runoff. The macropore system remained intact with no-tillage (Chan and Mead 1989).

While the degrading effects of tillage on soil structure is well documented, less is known about the structural effects of no-till into sod. Since no-till reduces carbon and nitrogen mineralization and does not distrub the soil structure, presumably the rate of structural decline would not be as great as it is with tillage. No-till does reduce the rate of structural degradation, especially at the soil surface, but the soil loses structural stability over time in either a tillage or no-tillage system because the carbon input from the roots is less than that from grass sod.

The exact degree to which no-till can prolong the benefits of grass is still an open question. It is known that no-till systems which produce abundant residues significantly improve the surface characteristics of previously tilled fields. This improvement is likely to lead to better infiltration and less erosion. Provision of optimum crop nutrients and use of cover crops with no-tillage causes production of additional residue and adds carbon to the soil. In a study in Kentucky, 20 years of fertilized no-till corn with a rye winter cover crop was able to restore the organic carbon content to that of a bluegrass sod (Ismail et al. 1994). Another study showed that it took only one moldboard plowing to eliminate 3 years worth of structural improvements achieved from no-till (Kladivko et al. 1986).

In eastern South Dakota on land that had been in alfalfa-bromegrass sod for 6 years, use of moldboard plow, chisel plow, and no-till corn production systems all gave similar yields (Lindstrom et al. 1994). In the fourth year of production, immediately after planting, artificial rainfall was applied at a rate of 2.5 inches/hr for 1 hr on each of 2 consecutive days to each system and to adjacent, undisturbed alfalfa-bromegrass sod. No water runoff or soil loss occurred from the areas still in sod or in no-till corn. An average of 49 percent of the water applied in the moldboard plow system and 34 percent of that applied in the chisel plow system was lost to runoff. Soil loss from the moldboard plow system was 11.8 tons/acre, and from the chisel plow system, 2.4 tons/acre.

In the northern part of the North Central Region conversion to no-till management from conventional tillage has in some cases resulted in temporary decreases in infiltration (Lindstrom et al. 1981, Mueller et al. 1984). However, no-till row-crop production systems following sod sustained much higher rates of infiltration than tilled systems following sod (Lindstrom et al. 1994). In the 6-year alfalfa-bromegrass study, improvement in organic matter, soil structure, and infiltration were maintained with no-till into the fourth cropping season, with no indication of soil degradation from continued no-till cropping. The no-till system promoted and sustained soil macropores that extended from deep within the root zone to the soil surface, where residue cover protected the openings from being filled with sediment. These macropores resulted in high infiltration rates, reduced runoff, and subsequently reduced soil loss.

Sorghum yields in the Texas Panhandle in 1993 were much higher from a no-till crop after grass sod than they were for sorghum in soil prepared by moldboard plowing the same grass sod (Unger, personal communication, 1994). Yields under chisel plowing were intermediate. The primary factor responsible for increased yield under no-till was increased water use efficiency. The no-till production system had no runoff, had less soil water loss early in the growing season from evaporation, and did not suffer as severely from water deficit at the critical period of flowering and grain filling.

Management Tips

Two prerequisites for achieving a cost-effective no-till system following CRP grassland are to completely kill the grass and to allow sufficient water to accumulate in the soil for germination and sustenance of the new crop. If the new crop is to be planted in the spring, the grass must be killed the previous fall or sooner, depending on when dormancy occurs (Smith et al. 1992). Systemic herbicides can obtain a good kill after the grass has been cut and begins vigorous regrowth. However, if the grass is dormant or under stress, which may occur in areas where water is limited in the summer and fall, then a systemic herbicide will give poor control. In these situations the grass must be killed by tillage or earlier application of the herbicide before water stress induces dormancy. If cool- and warm-season grass species are growing together, two applications of a systemic herbicide may be needed to avoid the two different dormant periods.

CRP permits farmers who grow winter wheat to plant in the fall and engage in some land preparation before seeding, including tilling up to 3 months prior to the October 1, 1995, release of the lands. By tilling, however, farmers disrupt the sod fabric, expose the soil to erosion, and promote rapid decreases in organic matter and infiltration. However, if they use an herbicide to accomplish the needed killing of the grass, the grass residues and sod will remain in place. This retention protects the soil from erosion during the period when it is accumulating water to germinate seed and facilitate crop growth. Many studies have shown that slowly decaying residues and sod keep infiltration rates high and control erosion for at least a year after the grass is killed.

Killing grasses with herbicides during the vulnerable early spring period when they are not water stressed and then leaving the residues on the surface achieves CRP objectives to maintain protective cover and production capability of the soil. However, at this writing CRP rule makers have not yet granted permission for such an early application; therefore this transition from CRP to no-till without tillage may not be possible without losing a year of production in the semiarid portions of the Great Plains. In most of the North Central Region, however, precipitation is usually sufficiently plentiful that there are periods during the summer and fall when there is no water stress so grass can be killed with herbicides. The local Soil Conservation Service (SCS) office has the most recent information available on permissible use of herbicides on CRP land during the last contractual year.

One challenge of planting on no-till CRP land is dealing with established burrowing animals and the damage they may have caused in 10 years. They may have left the soil surface quite rough (Kalisz and Stone 1984). One might want to moldboard plow the area before starting no-till, and in extreme situations this may be required. Normally, however, tillage is not needed. Once the grass is killed and a crop has been planted, the food source is removed, the animals disappear, and the mounds tend to level within the year.

Nitrogen management on no-till CRP lands needs special attention because of changes in nitrogen mineralization patterns (Wood et al. 1991a, 1991b; Lamb et al. 1985). When tillage is imposed on sod, a flush of microbial oxidation and mineralization of organic nitrogen may occur. Less intense tillage decreases the microbial oxidation of organic matter, and more of the organic nitrogen stays in the soil organic matter. Soil testing is critical. Any soil fertility recommendation must take into account the effects of the 10-year period of grass and the lack of a primary tillage operation. No-till into sod initially requires higher nitrogen rates than moldboard plowing does (Thomas et al. 1973).

Designing a No-Till System

A no-till system must be designed according to the unique conditions of the region and the specific needs of the individual producer. To be successful it must be developed with the whole system in mind. When designing a system, three broad principles that need to be considered are *rotation, sanitation,* and *competition* to help control weeds, insects, and pathogens (Beck and Doerr 1990) (also see chapter 5). Although the specific cultural practices required for each region and farm are likely to vary depending on climate, crop, and local markets, the three principles are common to the successful establishment of all no-till crops.

Sanitation

Sanitation involves practices that reduce the movement and spread of pests, such as weeds, diseases, and insects, into a field. An example of sanitation is mowing to prevent perennials from producing seed in field borders. Another example is the use of disease-free seed. Following the agronomic practices of sanitation is more critical in no-till systems than in other tillage systems, which can help reduce levels of some pests.

Rotation

Rotation can be beneficial in controlling weeds, diseases, and insects by breaking life cycles that depend on compatible crops or by increasing the competitive pressure on a pest during part of the rotation. An example is a rotation of corn, small grain, and soybeans to protect against corn rootworm infestations with extended diapause.

Rotations in no-till generally help create a stable, low-maintenance cropping system. When designing rotations, one should consider optimizing the cropping sequence for control of diseases, weeds, and insects, the soil temperature at planting, the moisture content of the seed zone, the residue cover for erosion control, and the labor and equipment.

Competition

Competition involves the ability of a crop to gain an advantage over weeds for light, water, and nutrients. An example of favoring a crop is the use of narrow row spacing to achieve earlier crop canopy cover. Cover crops may also be used in more humid regions to compete with weeds, add nitrogen, and protect the soil when cash crops are not growing.

Other Considerations

No-till equipment is designed for most crops. Care still needs to be used in machinery selection to ensure compatibility with approved methods of chemical application.

Farmers may find they need to modify their equipment, depending on climate and specific soil problems. For example, in the northern parts of the Corn Belt and the Cotton Belt, row-clearing attachments may be needed to remove some of the residue from the row area.

Other factors that should be considered when designing a no-till system include equipment use, livestock needs, the producer's preferences, cash flow requirements, available markets for specialty crops, predictable climatic patterns, proximity of the water table to the surface, soil fertility, and risk management. Those who are planning for no-till should study management practices and equipment adapted to the region, and they must develop practices and modify equipment suitable to the unique characteristics of their individual sites.

Conservation Measures for Residue-Deficient Crops

When the primary cash crop is residue deficient, there may not be sufficient residue during the year to provide the mandated erosion control. Examples of residue-deficient crops include edible beans, soybeans, sunflowers, cotton, and many vegetables. (Also see chapter 12 about crops that produce little residue.) Grass hedges, which reduce wind velocity at the soil surface and trap stray soil particles mobilized by the wind, can complement no-till management to achieve the needed control (Aase and Siddoway 1976). The grass in these hedges should be stiff stemmed and tall to provide significant protection of the soil immediately behind the hedges. As a rule of thumb, significant reduction in wind velocity is limited to 10 times the height of the hedge. In the few cases where the grass planted in CRP lands has tall, stiff stems (for example, switchgrass or tall wheatgrass), the hedges can be achieved by leaving living strips of grass 2 or 3 feet wide between planned, cropped strips that are about 10 times wider than the grass height.

If grass on the CRP land is not stiff enough and tall enough to sufficiently reduce wind velocity, CRP rules allow the cover to be improved during the contract period. Most perennial grass species require about 2 years to reach full height and to get their roots below those of annual crops. So hedges of tall grass are more likely to thrive and protect crops if planted 1 or 2 years before the crops.

To plant the hedges, first kill the grass strips in the CRP land with herbicides and then sow these strips with the desired grasses. CRP contract rules permitting, the short grasses between the hedges may be killed when the hedges reach the desired height and in preparation for planting the crop. To avoid violating CRP rules, it is important to discuss all plans for installing tall grass hedges with an SCS district conservationist.

CRP does not share the costs of controlling erosion with tall grass hedges on contract land, but the cost for herbicides and seed is small since less than 10 percent of any contract area will be in hedges.

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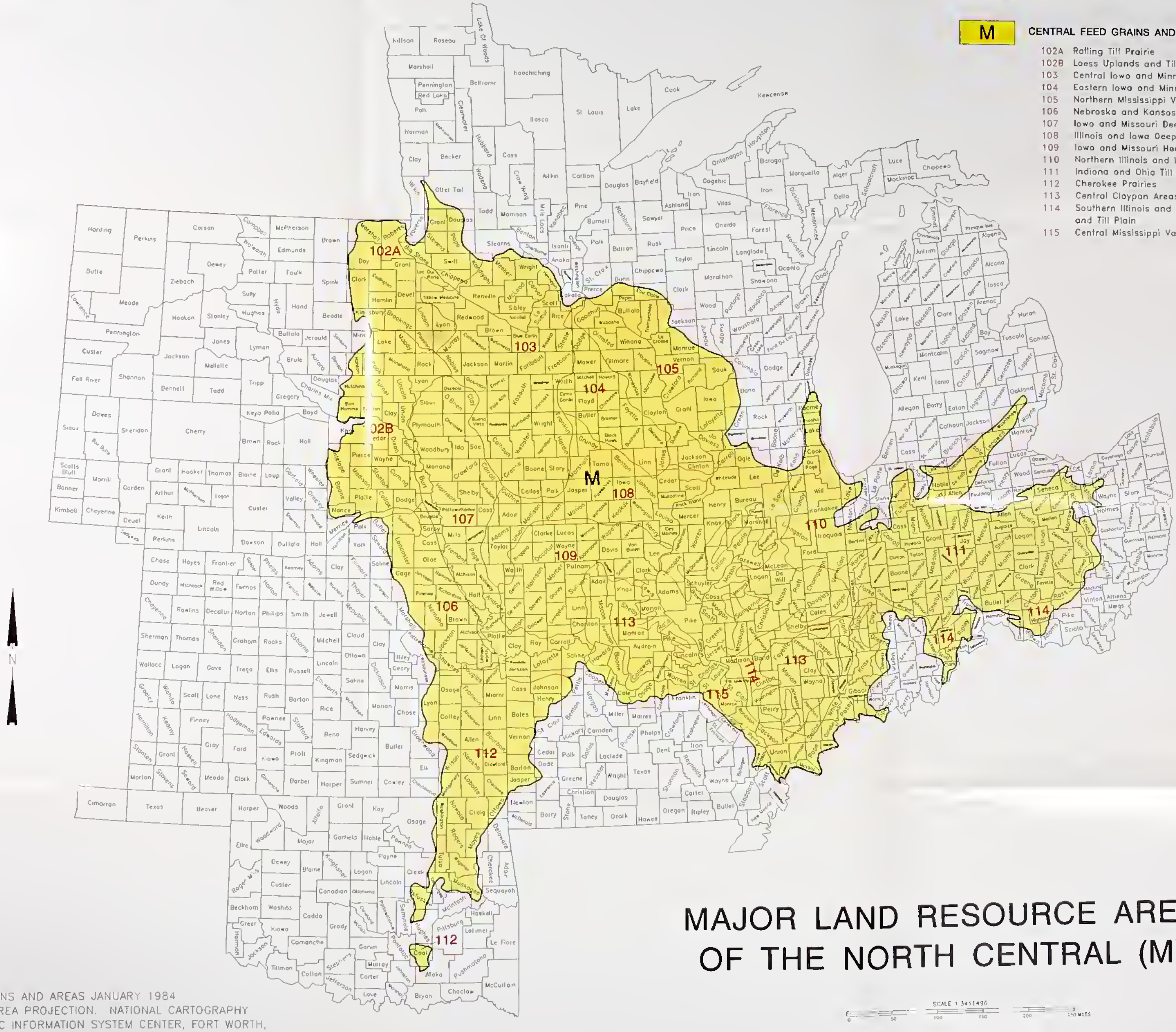

M	CENTRAL FEED GRAINS AND LIVESTOCK REGION
102A	Rolling Till Prairie
102B	Loess Uplands and Till Plains
103	Central Iowa and Minnesota Till Prairies
104	Eastern Iowa and Minnesota Till Prairies
105	Northern Mississippi Valley Loess Hills
106	Nebraska and Kansas Loess-Drift Hills
107	Iowa and Missouri Deep Loess Hills
108	Illinois and Iowa Deep Loess Hills
109	Iowa and Missouri Heavy Till Plain
110	Northern Illinois and Indiana Heavy Till Plain
111	Indiana and Ohio Till Plain
112	Cherokee Prairies
113	Central Claypan Areas
114	Southern Illinois and Indiana Thin Loess and Till Plain
115	Central Mississippi Valley Wooded Slopes

MAJOR LAND RESOURCE AREA OF THE NORTH CENTRAL (M)

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